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DECEMBER 1951

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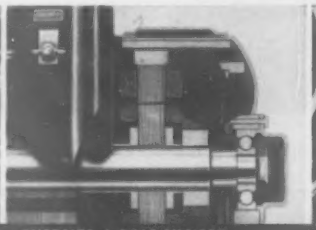

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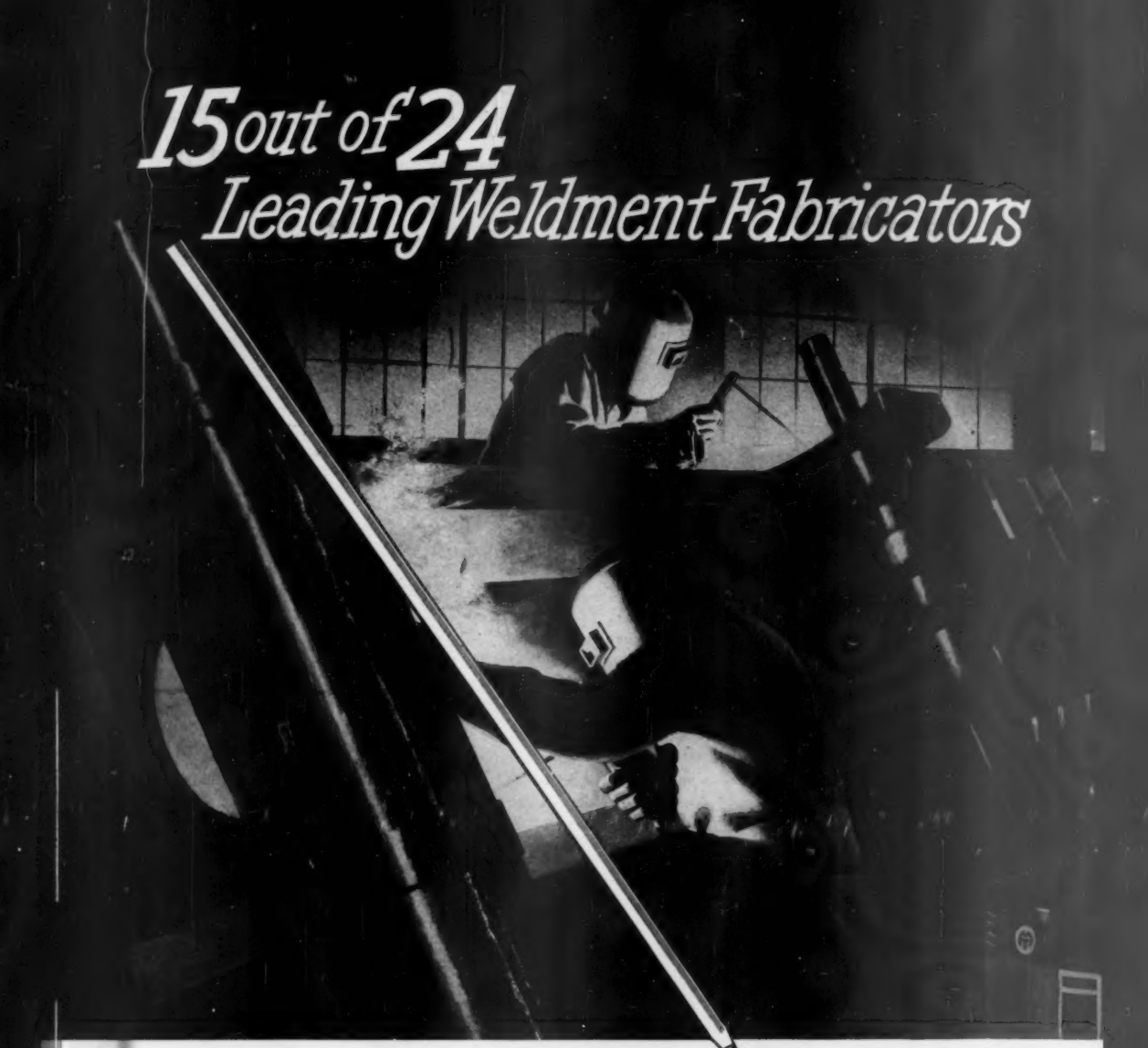

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The WELDING JOURNAL

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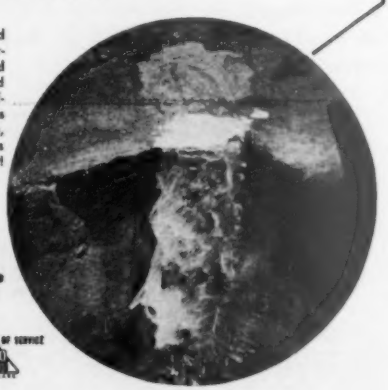

The WELDING JOURNAL

volume 30 December 1951 number 12

Spot and Projection Welding Using Magnetic Electrode Force

Electrode pressure in spot and projection welding applied by means of an electromagnet in the welder secondary circuit

by Wm. E. Klingeman and Harold H. Kruer

INTRODUCTORY SUMMARY

A NEW tool for joining ferrous and nonferrous metals is showing many advantages in the spot and projection welding field. This important development of applying pressure to the electrodes of a resistance welding machine by application of an electromagnet incorporated in the welder secondary circuit, has now advanced from the laboratory to the production-tool stage. In the use of this new welding process, the extremely accurate current-force-time relationship has made it possible to weld previously difficult and critical applications with a new degree of uniformity. Presently, the process is mainly being used for the welding of pure silver, coined silver and tungsten electrical-contact work, although within recent months, advantages have also been found for many other applications involving brass, copper and stainless steel.

With this process pressure build-up upon the work is exceptionally rapid and consistent with actual current flow. Therefore as the contact resistance of the workpieces vary, the electrode pressure applied by the electromagnet unit varies thus tending to compensate to a similar degree. The inherent characteristics of an electromagnet and the automatic compensating function as applied by this process are the major factors contributing to its success as a production tool.

Explanation of the process development performance data and machine characteristics are now made available with the thought to further the art of welding and development of automatic compensating type of welding equipment.

Wm. E. Klingeman and **Harold H. Kruer** are connected with the Precision Welder and Machine Co., Cincinnati, Ohio.

Paper presented at the Thirty-Second Annual Meeting, A.W.S., Detroit, Mich., week of Oct. 15, 1951.

DEVELOPMENT OF PROCESS

In the past, many years of time and effort have been used to develop the technique of resistance welding, perfect the welding machines and improve accuracy of the control equipment.

One of the chief aims during these development years was a means of synchronizing the three basic requisites of resistance welding; namely, magnitude of the welding current, electrode pressure and duration of current flow. Many times only a small change within any one of these three variables, or a change in a number of other variables, could result in a defective weld with no warning to the operator.

Five years ago, during a welding discussion, an idea was conceived as a possible means for controlling these variables. This new idea for a positive current-force-sime relationship involved applying the electrode presture through utilization of the passage of electrical current through the primary and secondary windings of a resistance welding type transformer. It was calculated that pressure would be applied as current started to flow through the windings and the time factor therefore would be in a definite relationship to the current flow.

Upon further consideration, an experimental welding unit was designed using an electromagnet energized by the secondary current circuit. This initial unit was unsatisfactory due to the use of straight alternating current on the electromagnet, resulting in a relaxation of electrode pressure as the alternating current passed the zero point of the sine wave. With additional experimentation, using single-phase half-cycle welding where

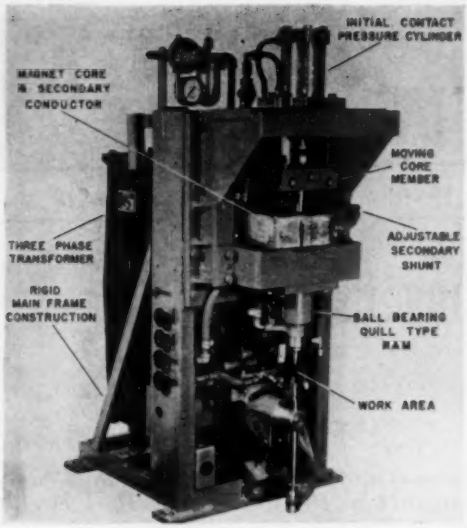

Fig. 1 Magnetic-force bench welder

the weld was completed by the time the sine wave crossed zero, the results gave increased encouragement and the first major problem was solved. Figure 1 shows one of the later experimental bench type machines; note the arrangement of the operating components.

This method had limitations as to over-all welding capacity; therefore it was decided to conduct additional laboratory experiments on the basis of three-phase welding so as to provide uninterrupted current and force for a longer duration. It was found by utilizing the three half-cycles of three-phase current and then repeating the process for a maximum of five cycles, which would be equivalent to 15 one-half-cycle pips, the weld time could be increased to handle the welding of heavier-gage stock.

This necessitated a special half-cycle three-phase control panel. Here again considerable development work was required in the design of the original electrical circuit. However, with further simplification through tests, the controls are now perfected and suitable for production. Figure 2 shows block-wiring diagram for operation with three-phase, 60-cycle power supply.

Gradually it was seen that a much superior weld could be obtained on many materials with this new form of resistance welding and Dr. I. W. Cox and Jerome Welch, with the aid of others, continued development work until a production tool was assured. It is not the intent, nor the belief, that magnetic electrode force welding will replace the conventional single- and three-phase welding technique; rather, to apply this type of process to the extremely difficult and critical applications so demanding of current, force and time relationship. At the time of this writing, a total of 12 production machines are now in operation in the field with 20 additional machines in process of manufacture. These machines are in addition to the original development machines utilized only for the experimental work.

DESIGN PRINCIPLES

Basically, the welding machine for either spot or projection welding, resembles the conventional direct-acting ram-type welder, including the air cylinder located directly above the ram. This air cylinder is used to lift the electrode the desired opening for work insertion and to provide the initial contact pressure of the electrodes to the work; thus completing the secondary circuit current path. Air pressure is made adjustable to provide

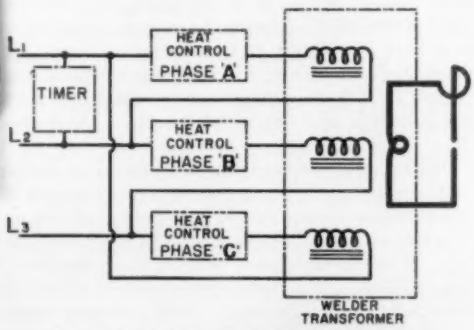

Fig. 2 Block diagram for three-phase circuit

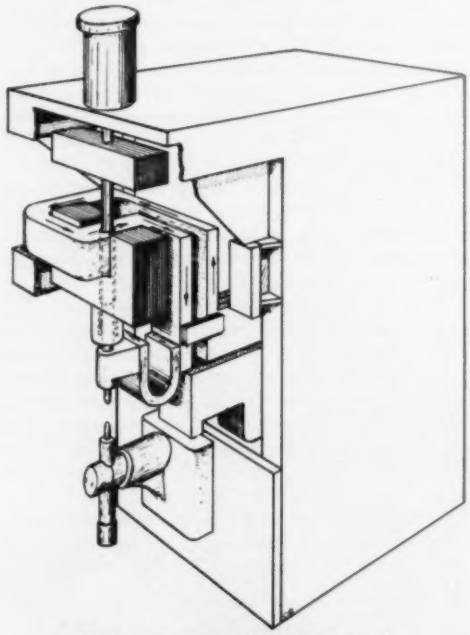

Fig. 3 Schematic of secondary circuit

varying contact pressure for materials having different resistances. Alterations, however, were required with both the electrical and mechanical design factors to accommodate the application of this magnetic pressure.

Magnetic pressures ranging from 50 to 3000 lbs. are now in general use and soon it will be possible to provide over 5000 lbs. of electrode force with machines under construction.

Operation consists of either the passage of single-phase or three-phase primary current through the primary coils of the special welding transformer, thus inducing lines of magnetic force that energize the secondary current path (secondary circuit), in a similar manner as conventional or three-phase welding machines. The major design change is made in the path of the secondary circuit. Instead of running the secondary conductors straight to the electrodes in the shortest practical path, one secondary conductor is

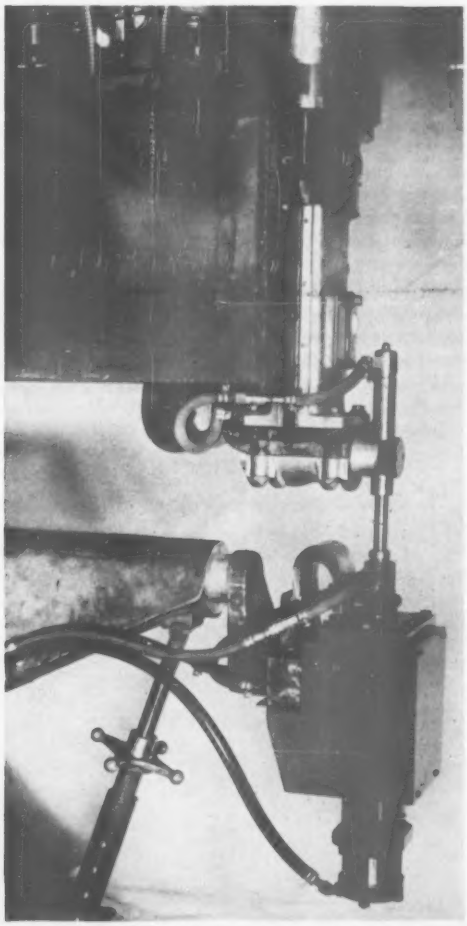

Fig. 4 Packaged knee-type magnetic-force unit

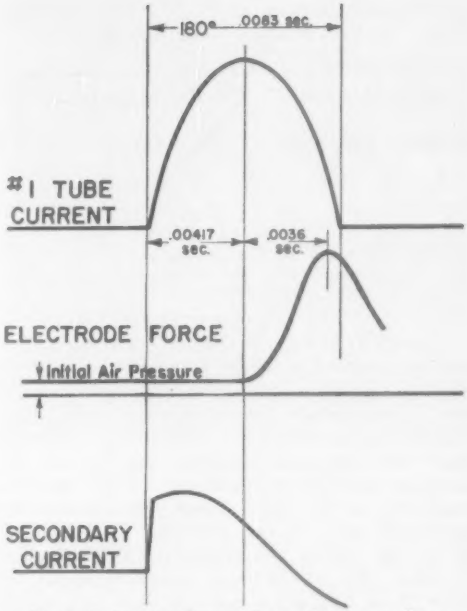

Fig. 5 Schematic showing firing of only one phase

directed to the split-iron-core magnet that is connected to the machine's main frame. Figure 3 outlines a simplified view of this secondary circuit. The moving portion of the core (clapper) is directly connected to the operating ram, while the remaining portion of the core is rigidly held to the main frame. See Fig. 1 showing the core-mounting method.

Variations in the position of the electromagnet and alterations in the arrangement of the secondary circuit have been made to further the flexibility of the unit. Figure 4 shows a magnetic-force unit designed as a package that can be inserted into the lower knee of a standard deep-throated spot welder. This particular experimental machine can be operated with either the conventional upper ram or the electromagnetic knee unit.

With secondary current flowing through the single turn in the secondary circuit, this split-core magnet is energized and the lines of force induced draw the split core together, thereby directly applying force to the welding electrodes. Pressure build-up is extremely fast after primary current initiation. Through laboratory tests (See Fig. 5 which shows only one phase of the three-phase circuit, therefore but one ignitron tube firing, along with the subsequent electrode force and secondary current build-up), the time lag between start of current flow and start of electrode pressure build-up is only 90 electrical degrees or a period of 0.00417 sec. Note that maximum pressure for this particular weld setting was reached in 0.0036 sec. after the start of pressure application.

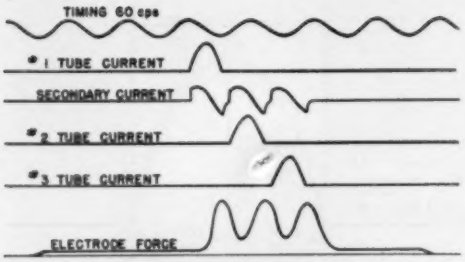

Fig. 6 Six-element oscillograph showing current-pressure-time relationship

Functionally, the operation of the welder is identical whether operated on single- or three-phase power supply, since only half-cycle firing is employed throughout. Design considerations in the manufacture of the welding transformer, however, require changes between single- and three-phase operation, and the point of maximum saturation of transformer core iron must be established on this basis. Figure 6 is a six-element oscillograph taken to show the direct relationship of three-phase welding with respect to current-pressure and time. No. 1, 2 and 3 tube currents, represent the three phases A, B and C and their firing relationship to the 60-cycle per second sine wave shown at the top. Note the secondary current trace for each of the three phases and the maximum magnetic-electrode-force build-up from the low initial air-pressure force.

Three important design factors govern welding machines using magnetic electrode force other than the special control circuits, etc. First, the machine must be exceptionally rigid to withstand the high pressures obtainable with the electromagnet with minimum deflection. This factor assures accurate alignment of finished workpiece and retains the advantage afforded by the process for consistent welds. Second, the ram movement should be designed for minimum friction. A ball-bearing quill-type ram of the reciprocating ball design has met this requirement satisfactorily. The third design consideration is with respect to the special welding transformer. With the use of half-cycle current, it was necessary to design a low-frequency transformer of the frequency-converter type requiring the large core iron section and its associated design factors, plus current considerations for operation of the electromagnet.

WELDING VARIABLES

Magnetic-electrode pressure adjustment is easily accomplished by one or both of the following methods: Adjustment of the air gap between the split-core magnet is very effective since pressure developed is inversely proportional to the square of the distance between moving portion of core and the stationary core member. In normal operation, a range from 0.065 to 0.187-in. air gap is used. As an added pressure adjustment, it is possible through the addition or subtraction of small copper shunt members, to govern the magnitude of current that in turn flows through that portion of the secondary circuit about the iron core of the electromagnet. For these shunt members 0.005-in. thick copper strip bolted across a secondary pad accomplishes the required shunting effectively.

VARIABLE	DIRECTION OF ADJUSTMENT	EFFECTIVE WELD HEAT	NET ELECTRODE PRESSURE
1. Initial Air Pressure	Increase	−	+
	Decrease	+	−
2. External Shunts	Increase	+	−
	Decrease	−	+
3. Air Gap of Electromagnet	Increase	+	−
	Decrease	−	+
4. Phase Shift Heat Control	Increase	+	+
	Decrease	−	−
5. No. of Phases Firing No. 1-2-3 Tubes	Increase	+	+
	Decrease	−	−
6. No. of Pips as in Repeat Operation	Increase	+	
	Decrease	−	

Fig. 7 Welding variables

A total of six main welding variables are available for selecting correct welding heat and pressure for any one type of spot or projection application. The following chart, Fig. 7, designates how each variable alters both, the effective heat for welding and the net electrode pressure on the work. Minus sign indicates less heat or less pressure while plus sign indicates additional heat or additional pressure for the particular adjustment contemplated. Normal setup requires but one or two adjustments.

SAFETY FEATURE

The magnetic-pressure welder features a safety knee device for operator protection. This knee performs the function of a backup and is unlocked until locked in position for welding by a solenoid operated latch (see Fig. 8). The locking solenoid is timed in electrically with the moving electrode by an adjustable

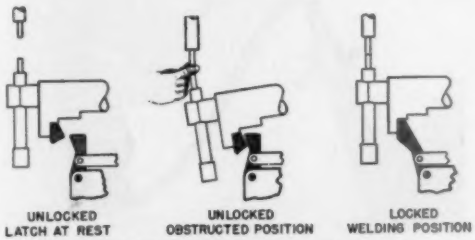

Fig. 8 Safety feature for operator protection

Pure Silver Contacts and Coined Silver Contacts	to	Bronze Strip Tin-Plated Brass Strip Cadmium-Plated Brass Strip Bare Brass Strip
18–8 Stainless Sheet	to	18–8 Stainless Sheet
Pure Copper Sheet	to	Pure Copper Sheet
Pure Copper Sheet	to	Tin-Plated Copper Sheet
Tin-Plated Copper Sheet	to	Tin-Plated Copper Sheet
Tungsten Contacts	to	Spring-Steel Strip
Tungsten Contacts	to	Low-Carbon Steel Sheet
High-Resistance Nickel Steel	to	Low-Carbon Steel Sheet
Bronze Sheet	to	Bronze Sheet
Low-Carbon 1010 Steel	to	Low-Carbon 1010 Steel
2S Aluminum Sheet	to	2S Aluminum Sheet
Red Brass (85% Cu)	to	Red Brass (85% Cu)
Yellow Brass (66% Cu)	to	Yellow Brass (66% Cu)
Zinc-Coated 1010 Steel	to	Zinc-Coated 1010 Steel
Magnesium Sheet	to	Magnesium Sheet

Fig. 9 Materials successfully welded using magnetic-electrode-force process

position limit switch. Consequently, if the moving electrode completes its travel, pressure is applied to the work and the latch locks in position. If however, an extra thickness of stock is unconsciously fed into the machine, or the work cocked, or the operator's hand or finger placed in the way of the electrodes, then no initiating of the limit switch or locking of the latch takes place. The safety knee holding the lower electrode is mounted upon antifriction pivot bearings for fast operation and accurate alignment.

RESULTS OBTAINABLE

A variety of materials have already been successfully welded and additional work is under way to further expand the range of material thicknesses and the basic metals and alloys that can be successfully welded. The chart Fig. 9 lists the combination of materials where tests have been conducted. Actual production, however, has mainly been confined to the pure silver and coined silver contacts welded to the various bronze or brass operating arm or fingers which are of strip material. Recently the welding of tungsten contacts to mild-steel or spring-steel operating arms and the welding of copper and brass strip material has reached the production stage.

Fig. 10 Typical projection-welded contact

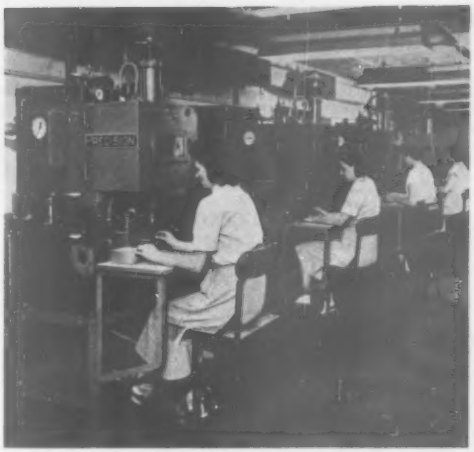

Fig. 11 Production view, projection welding electrical contacts

It was found early in the development stages that definite advantages were obtainable with the use of magnetic-electrode force for projection welding. Figure 10 shows a magnified view of a typical projection welded contact sample after peal test.

Results obtained through production projection welding such as the group of machines shown in Fig. 11, have now warranted the installation of many more additional machines to further advance magnetic-force welding in this one particular plant.

In the conventional projection welding process, the value of current flowing through the work contact surfaces is not always constant. While this fact is well recognized, it is a difficult problem to correct other than by the use of elaborate, expensive control equipment. In the welding of single-button-type projections, the magnitude of current flowing through the contact surface may change from one weld to the next, due to variations in electrical resistance caused by inconsistent projection shape and diameter, and differences in the pressure imprint of the projection in the opposite workpiece. Likewise, current density values change as the follow-up pressure causes deformation of the projection with a resulting change in contact area.

In the welding of multiple projections by conventional means, variations in projection height are always a factor of great importance. This condition causes the initial current to flow through the few highest projections. This extremely high current density in a few projections, rather than equal current flow in all projections, results in "blowing off the high projections and expulsion of metal."

The limited study to date on projection welding by the magnetic force process indicates a tendency to automatically compensate, in part, for these previously mentioned variables. As larger magnetic-force ma-

chines are developed, future experimental work is planned for multiple-projection welding applications.

Variations in surface resistance, due to the rapid formation of oxides on certain types of material, the variations caused by the adherence of grease, dirt and other foreign matter, are also minimized with this new process.

ADVANTAGES USING MAGNETIC-ELECTRODE-FORCE PROCESS

1. Current-force-time relationship assures uniform, consistent welds.
2. Greatly improved electrode life due to fast follow-up and short weld time. Some examples show up to 25 times previous electrode life.
3. Less marking and indentation upon workpieces, thus permitting greater acceptance of welding.
4. Maintained follow-up of electrode pressure results in less spitting of the weld metal.
5. Nonlifting of the electrodes at time of current flow. Many times found in conventional machines due to reactive kick in secondary circuit.
6. Tendency for automatic compensation of welding heat during line voltage changes, thus reducing the effect of a critical welding variable.
7. Tendency for automatic compensation of welding heat due to electrode variations such as "mushrooming" electrodes or misaligned electrodes.
8. No appreciable effect from changes in air-line pressure variation.
9. Increased pressure for automatic forge action since the air gap between armature and magnet decreases during the yield of the spot weld nugget or the collapse of the projection button.
10. Tendency for polishing surface of electrical contacts during coining action.
11. Accurately sizes the projection welding part. Production parts have been held within 0.002 thickness variations consistently.
12. Permits a low initial contact pressure thus making it possible to have a relatively high contact resistance and rapid heating of the weld area followed by the forging or coining action for completing the weld.
13. Greater weld consistency results in decreased inspection and decreased rejected work.
14. Minimizes pickup of coated materials upon face of electrodes.
15. Minimizes inertia factor of moving parts.
16. Permits use of the lower cost, softer copper-alloy electrode materials.

CONCLUSION

The conclusions that this magnetic-electrode-force machine and process offer certain favorable characteristics never previously approached with conventional resistance-welding machines are:

1. Its wide acceptance as a process that can provide consistent high-quality welds.
2. Its extremely accurate current-force-time relationship has proved it possible to weld a number of critical welding applications considered impractical before this development.
3. While this machine is especially adapted for the welding of materials of relatively low resistance and small mass such as welding silver contacts to brass contact fingers, it is not thus limited.
4. The art of resistance welding has been further expanded by development of this automatic compensating type of process and equipment.
5. Development and test of larger magnetic-electrode-force machines is justified and necessary to better understand and evaluate the welding of heavier gages and multiple projection applications.

Discussion "Magnaflux Inspection of Welded Storage Tanks"

Discussion by Franklin S. Catlin, Jr.

Mr. Upson's comments relative to the discussion by Mr. Schnurmann of Manchester, England, are fully correct. For some fifteen years or more we have been working with companies and doing intensive work in our own laboratories using *both* the wet magnetic particle bath which they call "magnetic ink" in England, and the dry magnetic powders which Mr. Upson discussed in his paper. We have, of course, kept a very critical eye on where each of the various materials applies best, and does the best job of inspection. Except where you are looking for fatigue cracks on large objects or the fairly gross surface cracks on weldments, the dry powder inspection is the most sensitive, quick and reliable in most large object inspections such as heavy castings and welded tanks.

There are two main points which make dry powder most useful on weldments: First, dry powders have much greater sensitivity for deep subsurface defects

(*Continued on page 1083*)

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Discussion by R. Schnurmann and author's reply appeared in the March 1951, issue of THE WELDING JOURNAL on pages 233–234.

The Effect of Power-Supply Characteristics on D.-C. Welding

Influence of variations in the slope of the volt-ampere curve in d.-c. welding on spatter loss, deposition rate and penetration

by Jack B. Keyte

Summary

A study was made of the influence of variations in the slope of the volt-ampere characteristic curve and the machine time constant of a d.-c. welding machine on spatter loss, deposition rate and penetration. All of the tests were run at the same operating point, using four motor-generator sets and a 36-volt battery circuit as power sources.

Instrumentation for this investigation involved the use of a 10,000-watt variable resistor to provide a variable load on the power source. In this manner the current and voltage could be measured accurately for plotting the characteristic curves. Also, a magnetic oscillograph was used in the determination of the time constant and the measurement of arc voltage and current.

The results of this investigation show that neither the slope of the volt-ampere curve nor the machine time constant influence the pattern of the welding operations studied in any definite manner.

INTRODUCTION

A CONTROVERSY has always existed concerning the regulation of the welding voltage and current during manual arc welding. Should an operator be allowed to choose the machine setting he prefers, or should the welding engineer attempt to control the quality of the weldment by designating the proper machine settings? The operator is responsible for the quality of workmanship, but the welding engineer is responsible for the cost, as well as the quality, of the weldment.

Another problem confronting the welding engineer in the selection of the type and make of a welding machine to be used in his organization.

Regulation of the welding current and voltage is accomplished by changing either the open-circuit voltage or short-circuit current, or both. As all welding machines have a drooping volt-ampere characteristic curve, a change in either the open-circuit voltage or short-circuit current will produce a change in the slope of the volt-ampere curve; this change being accomplished by varying the control settings. Volt-ampere curves are an evaluation of the steady-state load characteristics of a machine.

When certain types of electrodes are used, the metal transfer across the arc gap is of such a nature that it causes frequent short-circuiting of the electrical system. Thus, the instantaneous values of voltage and current may not vary according to the static volt-ampere characteristic, but are affected by the transient characteristics of the system.

Therefore the purpose of this investigation was to determine, to some extent, the effects that the slope of the static volt-ampere characteristic and the inherent transient characteristic produce on the welding operation. The factors selected as parameters in studying these effects were the penetration, deposition rate and spatter loss.

POWER SUPPLIES

Five different power supplies were used in this investigation. Two of the welders used were the dual-control type and will be referred to as power supply No. 2 and No. 4. A typical dual-control machine will have an open-circuit voltage varying between 50 and 100 v. and a short-circuit current varying between 100 and 600 amp., depending upon the rating of the machine. Consequently, there are many machine settings possible for the same arc voltage and current.

Two current-controlled machines were used and will be referred to as power supply No. 1 and No. 3. The open-circuit voltage varies between 60 and 80 v. and the short-circuit current varies between 100 and 400 amp.; however, for any particular welding voltage and current, there is only one machine setting possible.

Power supply No. 5 was an experimental battery circuit. The open-circuit voltage was fixed at 36 v. and the resistance and inductance were so adjusted that satisfactory welds could be made.

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Paper presented at the Thirty-Second Annual Meeting, A.W.S., Detroit, Mich., week of Oct. 15, 1951.

OPERATING POINTS

Operating points were chosen to correspond with recommended voltages and currents for the electrodes used. They were 22 v.–150 amp., 25 v.–190 amp., and 28 v.–250 amp. As the results of the welds made at all three operating points were similar, only the results of the 22-v.–150-amp. operating point will be discussed. The higher operating points gave more penetration and spatter loss, and a higher deposition rate.

ELECTRODES

Coated electrodes of-the E-6011 series and bare electrodes, E-60XX, were used in this study. In order to measure the spatter loss and deposition rate, it was necessary to know the weight of the filler metal before and after welding. The coating was removed from 20 electrodes and the weight recorded. The average weight was used for all of the tests involving the coated electrodes. Although it was not the purpose of this investigation to study electrode characteristics, it was interesting to note that the bare electrode had a higher deposition rate and lower spatter loss than did the coated electrode. However, the coated electrode gave better penetration.

STATIC VOLT-AMPERE CHARACTERISTICS

The necessary volt-ampere curves for the various machines used in this investigation were plotted in order to find the slope through the operating points. A 10,000-watt variable resistor was used to load the welding machines in steps to secure data for plotting the curves. The voltage across the load was measured with a 75–150-v. d.-c. voltmeter and the current was measured by using a calibrated shunt and a 1.5 v. d.-c. voltmeter. A knife switch was placed in parallel with the load resistor so that when the switch was closed, short-circuit conditions were simulated. It was interesting to note that each machine had a distinctive warm-up time varying between $^1/_2$ min. and 30 min. Before any tests could be run, the machine was operated for this time under load in order to insure constant voltage and current output at a given setting for test purposes.

On current-control machines there was only one curve through an operating point; however, there are a number of possible curves that will contain an operating point on a dual control machine. On the dual-control machines used, curves were elected with a steep slope, a flat slope and one falling between these two (Fig. 1). The slope of the curve was obtained by drawing a tangent to the volt-ampere curve at the operating point.

It can readily be seen, that for different slopes of these curves, the change in current for a given change in voltage will vary. During welding the operator may vary the length of the arc and, hence, vary the

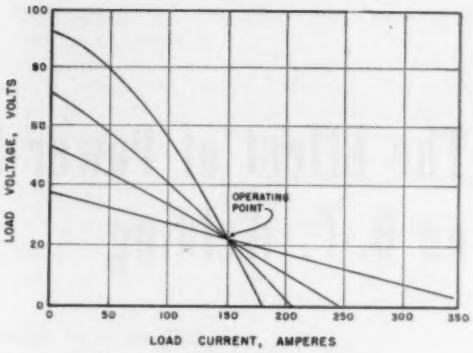

Fig. 1 Typical volt-ampere curves

voltage. This means that a corresponding change in current will take place and a new operating point on the volt-ampere curve will be established. It must be remembered that the volt-ampere curve is a representation of the static electrical characteristic and the values therein are the average voltage and current of the arc. The arc itself is in constant dynamic change. The magnitude of the current change can be affected by the time constant, length of short circuit—occurring when the metal is transferred—the current overshoot and the voltage recovery.

TRANSIENT CHARACTERISTIC

The transient characteristic can best be studied by means of the time constant, or ratio of inductance to resistance in the welding machine. It is important as it controls the time for steady-state current conditions to prevail when there is a change in the voltage. The time constant, which is actually the l/r ratio for the simple equivalent circuit, is equal to the time it takes for the current to reach 63.2% of its maximum change.

Since the best study of the time constant is made using an oscillograph, a seven-element magnetic oscillograph was used in this investigation, with recordings being made of 10-ft. rolls of verichrome film at a film speed of $2^1/_2$ ft. per second, or $^1/_2$ in. per cycle. Five galvanometers were used; two being used for reference lines for voltage and current, one used for load voltage, one for load current and a 60-cycle timing wave was put on the fifth element.

In order to insure that the time constant was measured for previously determined machine settings, a check was made of the volt-ampere curve before testing at a given setting.

Several procedures for measuring the time constant were tried and the following technique was adopted and proved to be satisfactory. A knife switch was connected between the electrode holder and the ground lead, and after the oscillograph camera had been in operation one second, the switch was closed for two seconds and then opened again.

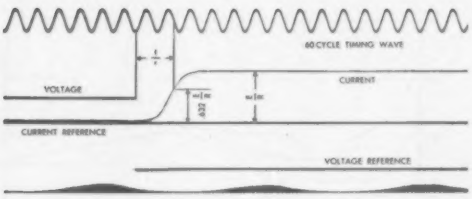

Fig. 2 Determination of machine time constant, 1/r

After the film was developed the time constant was determined by measuring the time, along the timing cycle, that it took for the current to reach 63.2% of its steady-state value after closing the short-circuiting switch (Fig. 2).

The per cent current overshoot and voltage recovery time could also be determined from interpretation of the oscillograph film.

WELDING PROCEDURE

All welding done during this investigation was performed by the same skilled welder. The welding time was measured by a stop watch and the voltage and current recorded on an oscillograph, although a recording voltmeter and a recording ammeter would have been sufficient. The machine settings were checked again to insure operation along a previously determined volt-ampere curve. All welding was done in the flat position on 2 × 3/8-in. bar stock. Five thirty-seconds inch diameter electrodes were used in all tests. A weld bead was laid down on each plate so that one electrode was used per test specimen; four specimens were welding for each machine setting.

DEPOSITION RATE

One of the performances a welding engineer is interested in is the deposition rate. Ordinarily this is thought of as a function of the electrode. It was one purpose of this investigation to determine if the electrical characteristics of the welding machine had any effect upon deposition rate.

The initial weight of the electrodes and the initial weight of the test specimens was determined and recorded. Also the time to make the weld on the test specimen was recorded. After welding, the test specimens were cleaned of all slag and spatter and reweighed. In this manner the amount of metal deposited was determined and the deposition rate in pounds per hour was calculated.

Graphs were made of the slope of the volt-ampere curve vs. deposition rate and time constant vs. deposition rate (Figs. 3 and 4). It was found that the deposition rate was not characteristically influenced by either the time constant or the slope of the volt-ampere curve. Certain optimum settings do exist, but it would appear that they can only be determined experimentally.

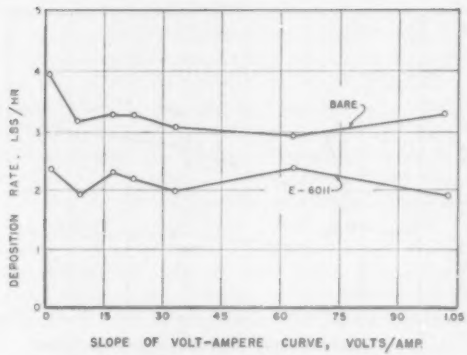

Fig. 3 Influence of slope of volt-ampere curve on deposition rate

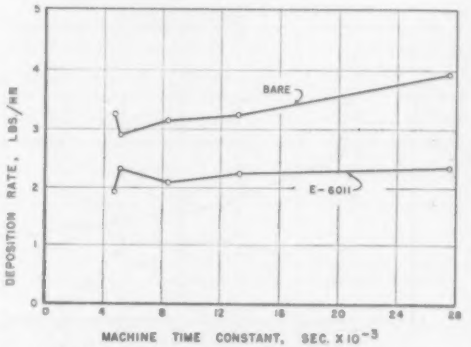

Fig. 4 Influence of machine time constant on deposition rate

SPATTER LOSS

Spatter loss is of concern to the welding engineer as it is material paid for that does no good, and often involves a further expense of removal. Once again the spatter loss is usually thought of as a function of the electrode, but only the effects of electrical characteristics were studied in this investigation.

In order to measure the spatter loss, it is necessary to know the amount of the electrode melted and the amount of electrode deposited. After welding, the electrode stubs were weighed and the difference between this weight and the original weight was recorded as metal melted. The ratio of metal lost during welding to metal melted is the spatter loss.

Graphs were drawn of the slope of the volt-ampere curve vs. spatter loss and time constant vs. spatter loss (Figs. 5 and 6).

It can be seen that the slope does not influence the spatter loss; there is a trend for lower spatter-loss values at higher time constants; however, tests at other operating points did not bear this out. Once again there were certain optimum values that were not predictable.

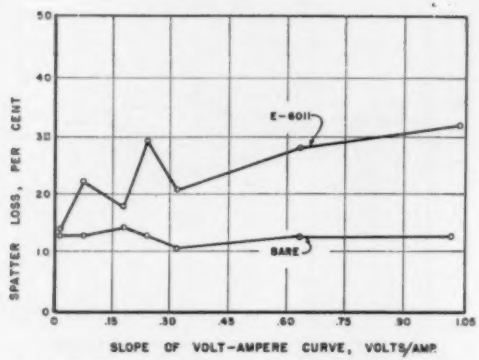

Fig. 5 Influence of slope of volt-ampere curve on spatter loss

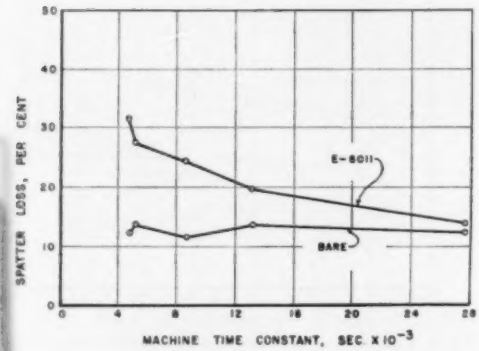

Fig. 6 Influence of machine time constant on spatter loss

PENETRATION

The quality of a weld is affected by penetration. Different series of electrodes have a more digging arc, hence deeper penetration; but it seemed worthy to investigate the effect of the electrical characteristics of existing welding machines on this function.

In order to measure the penetration, the test specimens were cross-sectioned, polished and etched. The depth of the molten puddle was then measured using a tube magnifier that was accurate to 0.1 millimeter. These readings were changed to inches for the sake of comparison with other investigations along these lines.

Graphs were plotted of the slope of the volt-ampere curve vs. penetration and time constant vs. penetration (Figs. 7 and 8).

It can be seen that penetration is not influenced by either of the electrical characteristics studied. Once again optimum values are noted, as was the case in deposition rate and spatter loss. However, there is no setting on any one machine that will produce optimum values for all three factors investigated.

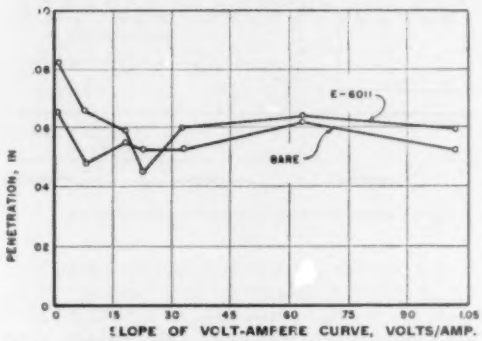

Fig. 7 Influence of slope of volt-ampere curve on penetration

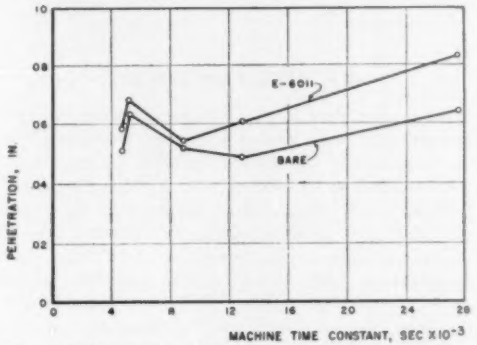

Fig. 8 Influence of machine time constant on penetration

VOLTAGE RECOVERY AND SURGE CURRENT

Evaluations of voltage recovery and surge current were made from the interpretation of time-constant oscillographs. It was noted that the voltage recovery time varied berween a few cycles and five seconds, and the values obtained were fairly constant for a given machine, regardless of machine settings.

In a similar manner the surge currents were found to be fairly constant for a given welder, regardless of machine setting. Values for the current overshoot varied from 130% to 240% of the steady-state value (Figs. 9 and 10). The battery circuit showed no current overshoot as it was a simple R-L d.-c. circuit.

CONCLUSIONS

These tests were run with machines that had an open circuit voltage varying from 36 to 100 v. The low open circuit voltage machine produced as satisfactory results as did the high open circuit voltage welding machine. This is contrary to the popular belief that a high open circuit voltage is necessary to strike an arc. It must be remembered that the low open circuit voltage machine was a test apparatus and could not be

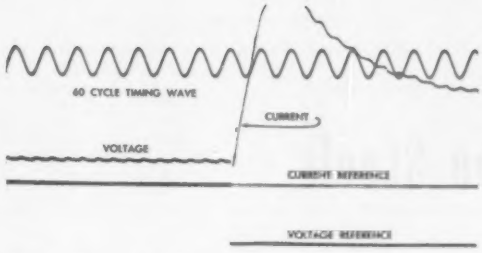

Fig. 9 Example of large surge current 191% of steady state

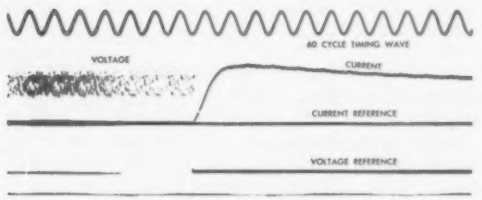

FIG. 10 EXAMPLE OF LOW SURGE CURRENT – 135% OF STEADY STATE

Fig. 10 Example of low surge current 135% of steady state

used for production. This machine also had a very low voltage recovery time and no surge current.

It was found that the electrical characteristics investigated, i.e., the slope of the volt-ampere curve and the time constant, did not influence the welding operations studied according to any definite pattern. Although a more extensive investigation may show some definite trends or patterns, it is quite clear that changing the slope of the volt-ampere curve seems to do no more than change the short-circuit current. Though it is apparent that the time constant has little effect upon the parameters studied, it is believed that it has appreciable effect upon arc stability, a phase which could not be covered in the time alloted to this investigation. There was no "cure-all" setting established for a machine through an operating point. However, if a welding engineer wishes to designate the correct machine setting to give him maximum penetration, for example, he may do so by having proper knowledge of his machine. It must be remembered that he may sacrifice low spatter loss or high deposition rate to get the desired results. It is hoped that this paper has outlined a method to gain this knowledge.

ACKNOWLEDGMENT

The work discussed in this paper was undertaken in the Department of Welding Engineering at The Ohio State University as partial fulfillment of the requirements for the degree Master of Science. The author expressly wishes to acknowledge the helpful and able guidance of Robert J. Krieger, Professor of Welding Engineering at that university.

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Discussion "Magnaflux Inspection of Welded Storage Tanks"

(*Continued from page 1078*)

(1/4 in., 1/2 in. or deeper) than do the wet Magnaflux baths. The wet bath is satisfactory on near-surface subsurface defects such as are found in aircraft engine part manufacture, but is not nearly as sensitive as the dry powder for the deep subsurface defects such as slag inclusions, or cracks in early passes on weldments. Secondly, a weld surface, or the surface of a large casting, is essentially rather rough. The wet bath particles tend to be held physically by ridges and roughness on these surfaces which gives you misleading accumulations of powder that are hard to differentiate from the indications of defects. Dry powder is practically not held at such surface roughnesses so that a build-up of dry powder can be known to be marking some type of discontinuity. Because of these reasons and others which Mr. Upson mentioned, we almost invariably recommend the use of dry powder for heavy weld inspection, especially during manufacture.

On lighter or smaller welds such as welded automotive steering components, or on welds which have been machined or ground smooth, such as propeller weldments, we do normally use wet Magnaflux bath where the above problems do not apply. Usually we now are using Magnaglo bath for such jobs since the fluorescent indications are brighter and clearer to speed up such high-volume inspection jobs.

On overhaul inspections which might be on some of the refinery equipment, but is more commonly on the weldments of truck or bus parts, or of aircraft landing gear, etc., we now very often use Magnaglo wet bath with a portable spray gun. This has high visibility and some speed advantage, and the above objections do not apply where you are looking only for fatigue cracks which are rather gross defects as compared to the very fine manufacturing cracks or the subsurface defects.

Sigma Welding of Carbon Steels

Successful welding of carbon steels by the shielded-inert-gas-metal arc process has been achieved by the addition of small amounts of oxygen to the argon gas

by H. T. Herbst and T. McElrath, Jr.

I. HISTORICAL BACKGROUND

ABOUT twenty years ago attempts were made to weld carbon steel with bare wire electrodes in an inert atmosphere, the results of which were reported in the Hobart and Devers patents. A sketch in this disclosure illustrated a bare rod fed through an argon or helium atmosphere. Due to the high cost of, and impurities in, the inert gas and lack of knowledge regarding current density, commercial application of the process was not established.

In recent years, however, the process has proved commercially feasible using a tungsten electrode and an inert gas shield. Most of you know this as inert gas-shielded arc welding. Magnesium and aluminum were the first metals welded; other metals followed. Recently the joining of carbon steel, particularly in the automotive industry, has been found to be practical.

Experience of several years using an inert atmosphere for welding with a tungsten electrode led to the development of the consumed metal electrode welding method, called "shielded inert gas metal arc" welding. This name has been shortened to "sigma," using the initial letters of the five descriptive words.

The first practical application of sigma welding was to aluminum. This proved to be commercially feasible. However, it was clearly desirable to apply this process to the welding of other metals.

Although stainless steel, copper and copper alloys could be successfully welded, initial trials of sigma welding of carbon steel with commonly used inert atmospheres were unsuccessful. Metal transfer and weld bead contour were poor, porosity and undercutting were prevalent, and costs were high due to slow welding speeds and the expense of the very small diameter welding rods that were found necessary.

Extensive research was conducted on altering the composition of the inert gas atmosphere. Earlier experiments on adding various liquid and gaseous components to the inert atomsphere in welding with a tungsten electrode indicated that the same line of research should be followed with the consumable electrode. When this was continued for sigma welding of carbon steels, it was found that excellent results were achieved through the addition of small percentages of oxygen to argon. What we found to be the most effective mixture is now marketed as Linde argon—sigma grade.

This mixture contains approximately 5% oxygen and 95% argon, and is available in standard-size compressed gas cylinders. Where a mixture containing less than 5% oxygen is desired, sigma grade argon may be mixed with pure argon using standard welding-type argon flowmeters.

The objective of this paper is to study the advantages of the argon-oxygen mixtures, and to describe developments in applying sigma welding to carbon steels.

II. PRACTICAL BENEFITS OF ARGON-OXYGEN MIXTURES FOR SIGMA WELDING

In order better to understand the character of the argon-oxygen mixture, comparisons will be made between the results obtained with it and the results obtained with pure argon and pure helium atmosphere. Early study using pure argon in the sigma welding of carbon steel indicated that with this gas, coalescence was poor, and undercutting occurred at relatively low welding speeds. With a helium atmosphere, spatter rate was high and arc stability was poor. However, substitution of the argon-oxygen mixture permits welding at higher speeds without undercutting, coalescence of the weld metal is improved at increased welding speeds, and good stability and low spatter rate are obtained.

The significant factor in adding oxygen to argon in the welding of carbon steel is the increase of rate at which drops of metal are discharged from the end of the welding electrode. This drop rate is in the neighborhood of 30 to 50 times higher in the argon-oxygen mixture than in the pure gas atmosphere, as determined by means of high-speed-motion picture photography.

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Paper presented at 32nd Annual Meeting, A.W.S. Detroit, Michigan, week of Oct. 15, 1951.

Table 1—Sigma Welding of Carbon Steel

Recommended Current Ranges—Amperes DCRP

Rod diameter, in.	*Argon, min.*	*Sigma grade argon*	
		Min.	*Max.*
1/32	130	100	175
3/64	225	130	250
1/16	300	200	350
3/32	375	320	500
1/8	...	400	...

This means that a stable melt-depositing condition spray-like arc can be obtained at much lower current densities in the gas mixture than in pure argon. Furthermore, this change of atmosphere aids the edges of a weld joint to flow together, improving weld metal coalescence.

Practical effects of these changes are:

1. Much lower currents can be employed for a given size of electrode, as noted in Table 1. This effect allows use of much lower current densities and selection of welding rod one or two sizes larger than possible when using pure argon.

2. Welding speeds are at least twice as high without encountering lack of coalescence, undercutting or porosity. For instance, in argon atmosphere, lack of coalescence occurs when welding 1/4-in. steel plate at 20 in. per minute thus restricting the speed to about 15 in. per minute. With Linde argon—sigma grade, speeds up to 30 in. per minute produce satisfactory welds.

3. Straight-polarity direct current welding is usable. In pure argon, straight-polarity current is practically unusable, but with argon-oxygen mixture satisfactory results have been achieved where minimum dilution and less arc blow are desired.

III. SCOPE OF PROCESS

It is possible, under some special conditions, to make satisfactory sigma welds on material as thin as 1/16 in. However, the process has an inherent characteristic which sometimes becomes a disadvantage—the heat required for fusion is more or less unalterably tied to the deposition of weld metal. In welding thin material the amount of rod melted is frequently considerably in excess of the desired amount. This is usually true in butt welds in material of about 1/8 in. thickness and less. In fillet and lap welds extra reinforcement is provided which meets the requirement for metal to produce the fillet. However, in butt welding materials thinner than 1/8 in., greater economy may generally be realized through the use of "Heliarc" welding because of the control that can be exercised over the amount of metal deposited.

Plate thicknesses of from 3/16 to 3/4 in. should generally be satisfactory for operation with the sigma process using beveled edges, while for heavier plates "U" grooves may offer economy through decreased weld metal requirements.

Sigma welding is applicable to low-alloy steels in these ranges of thickness. Killed or semikilled materials are readily handled by the process, but porosity may be a factor in rimmed type steels. Laminated steels are more difficult to handle and will produce more porosity than sound plate. However, this problem is not particularly different with the sigma welding process than with other methods of welding. It should be noted that the process shows considerable promise for those alloy steels of composition subject to underbead cracking associated with hydrogen. Here, as with the "Heliarc" process, the absence of hydrogen is particularly effective in preventing underbead cracking.

For low-carbon steels, that is, less than 0.10% carbon, a weld with approximately the same carbon content will be obtained using rod of substantially the same composition. Where the carbon content of the rod is in the neighborhood of 0.30%, there may be a 15 to 20% loss of carbon in transfer across the arc. Therefore, where heat treating requires maintaining in the weld metal the same carbon content as in the base metal, the rod should have more carbon than is required in the weld.

IV. EFFECT OF VARIABLES

General

Having once established the suitability of base metal and rod compositions together with the necessary welding conditions and plate-edge preparation to produce acceptable welding joints, there are certain other variables which have a noticeable effect on the completed weld. The purpose of this section is to describe the effect of many of these operating variables, particularly in regard to their effect on porosity and penetration.

Table 2—Sigma Welding—Effect of Argon Flow Rates on Porosity

Sigma grade argon flow, cu. ft. per hour	*Porosity count in 12 in. of weld*
20	Extreme visual porosity
30	Scattered heavy porosity
40	One hole
50	One small hole
60	One hole
70	Two very small holes

Effect of Gas Flow on Porosity

The influence of shielding gas flow rate may be shown by results obtained at various gas flows using machine welding conditions for welding 5/16-in. plate noted in Table 6. A gas flow rate of 20 cu. ft. per hour results in gross porosity visible on the weld surface. Increasing the flow rate to 30 cu. ft. per hr. removes visible porosity, but radiographic examination reveals many voids in the weld. A gas flow rate of 40 cu. ft.

per hr. produces essentially porous-free welds. A flow rate of 50 cu. ft. per hr. provides a reasonable safety factor. Higher flows of 60 and 70 cu. ft. per hr. do not have a deleterious effect on the weld. Table II indicates the radiographic results at the various gas flows.

Relation of Arc Voltage to Incidence of Porosity

As mentioned previously, incidence of porosity depends on adequate gas protection. When the welding rod is curved as it emerges from the welding gun, the effectiveness of the gas protection is lost if the arc due to curved rod is displaced too far from the center of the gas pattern. When the welding rod is relatively straight and the arc is therefore centrally located in the gas shield, the incidence of porosity is not affected by arc voltage over the range of from 24 to 32 volts. Very low arc voltages will, however, result in formation of porosity when the arc is not centrally located in the gas shield. It is therefore good practice to avoid the use of arc voltages of less than 26.

Effect of Current Density on Porosity

A series of beads on $^{5}/_{16}$-in. plate were made under identical conditions except for rod size which was varied from $^{3}/_{64}$- to $^{5}/_{16}$-in. diam., inclusive. Radiographic examination of these beads revealed a strong tendency toward formation of porosity with the $^{3}/_{64}$-in. diam. rod and a somewhat lower tendency with the $^{1}/_{16}$-in. diam. rod. Beads made with the larger rod sizes were virtually free of porosity. Table 3 tabulates the welding conditions and results. From this simple test it might be concluded that current densities should be well under 98,000 amp. per sq. in. to eliminate porosity. Sigma grade argon which allows the use of larger rod sizes is of considerable benefit in establishing good operation under these conditions.

Table 3—Effect of Current Density on Porosity

Steel Rod Diameter, in.	*Current density, amp. per sq. in.*	*Porosity count in 20 in. of weld*
$^{5}/_{16}$	11,000	No holes
$^{1}/_{8}$	25,000	One small hole
$^{3}/_{32}$	44,000	No holes
$^{1}/_{16}$	98,000	Ten small holes
$^{5}/_{64}$	170,000	Scattered small holes completely throughout weld

Plate thickness, in.	$^{5}/_{16}$
Plate type	Fully killed
Type of weld	Flat beads
Current, amp., DCRP	300
Welding speed, in. per minute	15
Arc voltage	26
Sigma grade argon flow, cu. ft. per hour	50

Effect of Speed on Porosity

To determine the effect of speed on porosity, a number of beads were made on grooved plates with all of the conditions held at fixed values except for the welding speed which was increased from 5 in. per minute in increments of 5 in. per minute.

Table 4—Effect of Speed on Porosity

Welding speed, in. per minute	*Porosity count in 12 in. of weld*
5	No porosity
10	No porosity
15	No porosity
20	Clear over $^{2}/_{3}$ length, heavy porosity last $^{1}/_{3}$ of length
25	Four areas of severe porosity
30	Lack of penetration and scattered porosity
35	Bad lack of coalescence

Plate thickness, in.	$^{3}/_{4}$
Plate type	Fully killed
Edge preparation	60 deg. vee included angle, $^{3}/_{4}$ in. deep
Sigma grade argon flow, cu. ft. per hour	50
Welding current, amp., DCRP	500
Welding rod, diameter, in.	$^{1}/_{8}$
Arc voltage, $^{1}/_{4}$ in. arc length	26

Table 4 illustrates the radiographic results which show that at a speed of 15 in. per minute and under, complete freedom from porosity is enjoyed. At 20 in. per minute, porosity becomes apparent at the finishing end of the weld. This end condition is presumably caused by magnetic disturbance of the arc as it approached the end of the plate. Using a current of 500 amp. on $^{3}/_{4}$-in. plate, speeds higher than 20 in. per minute produce several difficulties—namely, scattered porosity, transverse stringer porosity and, at the higher speeds, a lack of coalescence along the weld edges.

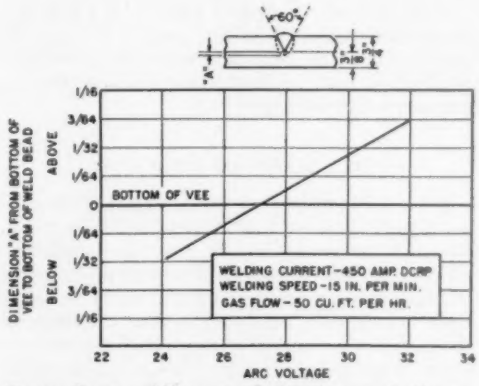

Fig. 1 Sigma welding: graph showing penetration vs. voltage. At an arc voltage of 27 or higher, no penetration is obtained below the bottom apex of the groove

Effect of Voltage on Penetration

A series of beads was deposited in grooves on $^{3}/_{4}$-in. thick steel plate using conditions listed in Table 4 except that welding speed was held at 15 in. per minute and welding current at 450 amp. in all cases. The arc voltage was altered for each run and Fig. 1 illustrates the manner in which penetration is influenced by arc voltage. At an arc voltage of 27 or higher, no penetration is obtained below the bottom apex of the groove.

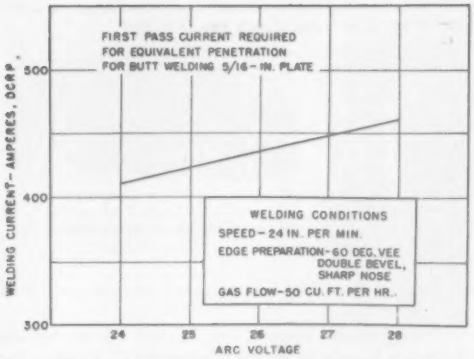

Fig. 2 The variation in current to produce a given depth of penetration as the arc voltage is changed when welding 5/16-in. thick plate. To secure equivalent penetration, considerably lower current can be employed at 24 v. than required at 28 v.

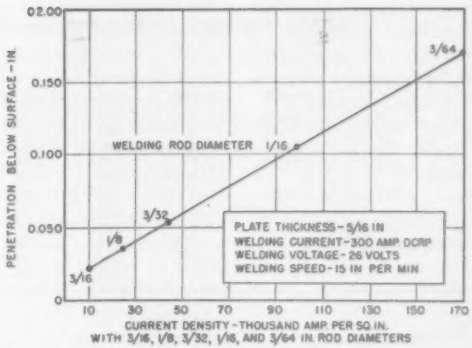

Fig. 3 Penetration is plotted vs. current density. At 10,000 amp. per sq. in., penetration below the surface is 0.020; for 170,000 amp. per sq. in., penetration is 0.170 in.

The effect of voltage on penetration may also be shown in terms of current required to produce constant depth of penetration with varying voltage. Figure 2 illustrates the variation in current to produce a given depth of penetration as the arc voltage is changed when welding 5/16-in. thick plate. It shows that, to secure equivalent penetration, considerably lower current may be employed at 24 v. than is required at 28 v.

Effect of Current Density on Penetration

Penetration measurements were made on a series of weld beads deposited on 5/16-in. thick plate using welding rods of from 3/64 to 3/16 in., inclusive. All conditions were constant except welding rod diameter. The plot of penetration versus current density, Fig. 3, illustrates a linear function of increasing penetration with increasing current density. At 10,000 amp. per sq. in., penetration below the surface is 0.020 in., while for 170,000 amp. per sq. in., it is 0.170 in. or about eight times greater.

V. WELDING PROCEDURE

Arc Control

Arc control in sigma welding may be exercised in either of two ways. Of these two, the simplest, from an equipment standpoint, employs a welding rod driven at constant speed. The maintenance of a constant arc length depends upon the natural self-regulating characteristics of the arc and the drooping characteristics of welding generators. This method of control is satisfactory for average hand welding work. The other method of arc control maintains a constant arc voltage by varying the rod feed as necessary. The second method, although requiring somewhat greater complexity of equipment, offers several advantages including:

1. More rapid correction especially at lower current densities.
2. Automatic compensation for varying generator output.
3. Ease of setting welding conditions.

This type of control is available in machine welding units.

Table 5—Conditions for Hand Sigma Welding of Mild Steel Using Sigma Grade Argon

Thickness, in.	*Type of weld*	*No. of passes*	*DCRP, amp.**	*Arc, v.*	*Gas flow, cu. ft. per hour*	*Welding speed per pass, in. per minute*	*Edge preparation*
1/4	Butt	1	375	27	40–50	24	60-degree double vee, sharp nose
		2	430	28	40–50		
5/16	Butt	1	400	27	40–50	20	60-degree double vee, sharp nose
		2	420	28	40–50		
5/16	Fillet	1	400	27	40–50	16	Nonpositioned
1/2	Butt	1	400	28	40–50	14	90-degree double vee, sharp nose
		2	450	28	40–50		
1/2	Fillet	1	450	28	40–50	12	Positioned
3/4	Butt	1	400–450	27–28	40–50	12	90-degree double vee, sharp nose
		2	450	28	40–50		
		3	450	28	40–50		
		4	450	28	40–50		
3/4	Fillet	1	450–500	29–30	40–50	9	Positioned
1	Fillet	4†	450	27–29	40–50	7	...

* For lower currents back-chip double-vee welds and increase number of passes on 1/2 in. and thicker.
† All stringer beads.

Table 6—Conditions for Machine Sigma Welding of Mild Steel Using Sigma Grade Argon

Thickness, in.	*Type of weld*	*No. of passes*	*DCRP, amp.*	*Arc, v.*	*Gas flow, cu. ft. per hour*	*Welding speed, in. per minute*	*Edge preparation*
1/16	Butt	1	300	24	50	40	Square butt
1/8	Butt	1	380	25	50	30	Square butt
3/32	Lap	1	380	26	50	55	Positioned
5/32	Butt	1	440	26	50	24	60-degree double vee, sharp nose
		2	460	26	50	24	
1/2	Butt	1	440	26	50	15	60-degree double vee, sharp nose
		2	460	26	50	15	
3/4	Butt	1	400	26	50	15	60-degree double vee, sharp nose
		2	400	26	50	15	
		3	430	26	50	15	
		4	430	26	50	15	

Technique

The edge preparation for a variety of plate thicknesses is shown in Tables 5 and 6. It should be noted that where bevels are indicated, zero nose thickness is specified as is common in flux-coated electrode welding. It is not necessary, however, with sigma welding to maintain a joint spacing.

The welding current for the root or first pass should be sufficiently high to produce a penetration bead visible from the opposite side. In cases of double-vee preparation, considerably higher currents should be used on all subsequent passes.

As previously mentioned excessively short arc lengths should not be employed. Such undesirable arc lengths are characterized by a sharp crackling or frying sound, and accompanied by excessive spatter. Satisfactory arc lengths generally appear to be about 3/32 to 1/4 in. in length. Excessive arc length reduces penetration and makes directional control of the arc difficult. First pass beads or welds made in one pass should employ shorter arc lengths than finishing passes.

In sigma welding the gas protection is important in X-ray quality work. Such protection is attained through a proper flow rate of gas, by centering of the rod and arc in the gas stream and by suppression of external magnetic disturbances which cause arc blow. Good practice in control of arc blow generally calls for welding in a direction away from the ground connection, and the use of adequate end tabs or other magnetic shunt.

The welding torch should be held so that the rod is substantially vertical to the weld. Continuous steady forward motion of the torch may be employed. For root passes, however, a slight backward and forward motion of the torch is used to aid in promoting coalescence and improve surface contour. For finishing passes on multipass welds, a slight weave may be used. Where bead width requires excessive weaving, multiple stringer beads are to be preferred.

Welding Data and Applications

Typical welding data for several plate thicknesses are shown in Table 5 for hand welding. Similar data applicable to machine welding operations are shown in Table 6.

Several recent applications of the sigma welding process will serve to illustrate some of the diverse ways in which the process may be used.

On certain designs of compressor housings, the possibility of flux entrapment with coated electrode or submerged arc welding favors the use of sigma welding. Figure 4 shows such a compressor housing design and a weld cross section. Welding data are given in Table 6. Sigma grade argon allows the use of 3/32-in. diameter rod on this 3/32-in. steel with direct current, reverse polarity.

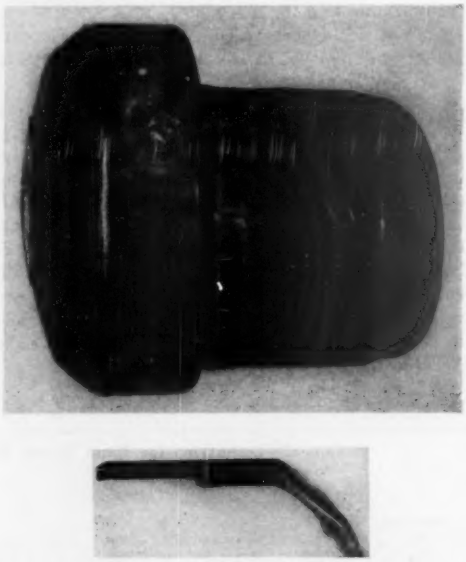

Fig. 4 Photograph shows a typical compressor housing and a weld cross section

An example of the use of the sigma process for a welded joint with direct current, straight polarity is in the fabrication of structural brackets of 1/4-in. plate. These brackets involve fillet welds joining plates in three planes. This plate geometry is conducive to excessive arc blow conditions using reverse polarity. The use of sigma grade argon made possible use of the straight-polarity connection and 1/16-in. diameter rod.

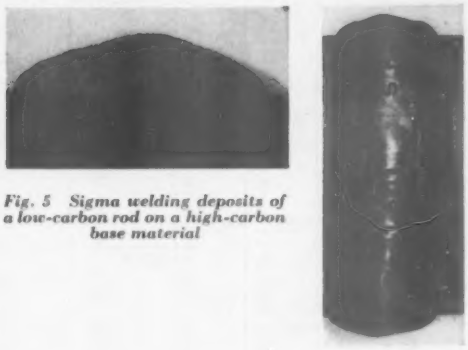

Fig. 5 Sigma welding deposits of a low-carbon rod on a high-carbon base material

This combination largely suppressed the arc blow trouble and allowed continuous welding into the compound corners. The average welding speed was 25 to 30 in. per minute for five $^1/_4$-in. fillets totaling 59 in. in length.

In addition to joining operations, proper selection of welding conditions makes possible build-up operations with a minimum of base metal pickup. This type of operation is best performed with straight polarity due to the ease with which base metal melting can be controlled. Figure 5 shows deposits of a low-carbon rod on a high-carbon base material. Average penetration is less than $^1/_{16}$ in. Using welding rod containing 0.028% carbon, a base metal containing 0.50% carbon weld metal analysis showed a carbon content of 0.11%.

A wide variety of bead shapes and deposit rates may be achieved through the use of a weaving technique and/or rod additions other than the electrode.

VI. WELD PROPERTIES

Radiographic Soundness

Under suitable operating conditions of speed and gas shielding, weld soundness depends on presence of deoxidizing elements. Killed, semikilled and rimmed plate welded with a rod containing deoxidizing elements will result in porous-free welds. In general, lower current densities must be used when welding rimmed plate than are permissible for killed material. The use of rimmed steel rods results in a tendency toward formation of gross porosity. It is interesting to note that, whereas rimmed type core material is generally used for flux-coated electrodes to obtain good discharge characteristics, either rimmed or killed rods have excellent discharge characteristics in the sigma grade argon atmosphere. However, in sigma welding, the use of rimmed rod is inadvisable because of greater tendency toward formation of porosity.

Mechanical Properties

Mechanical properties of sigma welds in steel depend principally on the rod composition and secondarily on the plate joint preparation. A low-carbon rod with manganese and of the killed type produces in $^3/_4$-in. plate welds having tensile strengths in the range of from 64,000 to 71,000 psi. The lower figures occur with 70-degree welding vees and lower current values, while a 50-degree vee and high currents produce higher tensile values. With this type of rod, mechanical properties and radiographic properties equal to those specified for 6010 and 6011 flux-coated electrodes are obtained. Higher strengths suitable for low-alloy steels and equal to mechanical properties of the 6012 and 6013 classifications are obtained with a rod similar to the above but having some chromium as an alloy. The radiographic quality of such sigma welds should, however, be somewhat superior to that normally expected from electrodes of the 6012 classification. This information is summarized in Table 7.

Table 7—Comparison of Mechanical Properties, Mild Steel Weld Metal (As-Welded)

	*Tensile strength, psi.**	*Yield strength, psi.**	*Elongation in 2 in., %*	*Reduction of area, %*
E6010, E6011	62–73	52–61	22–28	35
Sigma weld with manganese-silicon killed rod	64–71	52–56	26–33	27–65
E6012, E6013	68–78	55–65	17–22	25
Sigma weld with manganese-silicon killed rod plus chromium	72–78	55–63	16–18	30–39

* Times 1000.

VII. ROD BURNOFF CHARACTERISTICS

Direct Current Reverse Polarity

The rate at which rod is consumed in the welding arc under any set of conditions is constant. This rate is referred to as the burnoff rate. In any given welding atmosphere this rate varies with the arc current, voltage and polarity. In the sigma grade argon atmosphere these relationships are shown in Fig. 6. Also on this figure is an additional curve showing burnoff for

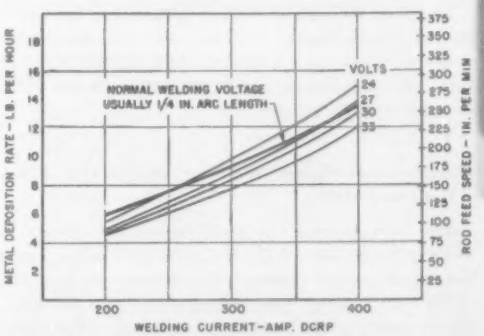

Fig. 6 Deposition rate and rod feed speed vs. welding current for sigma welding of carbon steel using $^1/_{16}$-in. steel welding rod

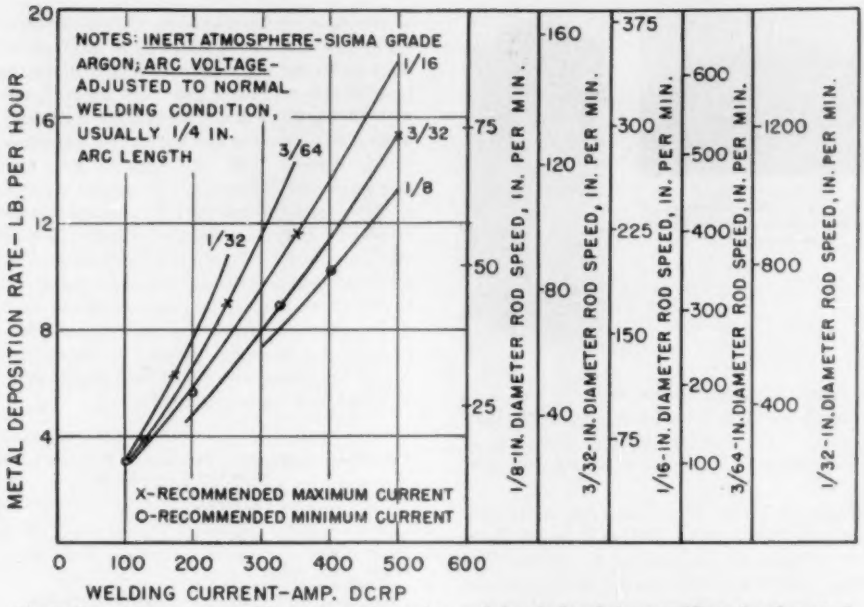
NOTES: INERT ATMOSPHERE-SIGMA GRADE ARGON; ARC VOLTAGE-ADJUSTED TO NORMAL WELDING CONDITION, USUALLY 1/4 IN. ARC LENGTH
1/16
3/32
3/64
1/8
1/32
X-RECOMMENDED MAXIMUM CURRENT
O-RECOMMENDED MINIMUM CURRENT
METAL DEPOSITION RATE-LB. PER HOUR
WELDING CURRENT-AMP. DCRP
1/8-IN. DIAMETER ROD SPEED, IN. PER MIN.
3/32-IN. DIAMETER ROD SPEED, IN. PER MIN.
1/16-IN. DIAMETER ROD SPEED, IN. PER MIN.
3/64-IN. DIAMETER ROD SPEED, IN. PER MIN.
1/32-IN. DIAMETER ROD SPEED, IN. PER MIN.

Fig. 7 Deposition rate vs. welding current for various rod sizes in hand sigma welding of carbon steel

normal welding voltage for $^1/_{16}$-in. diameter rod. This curve, together with similar plots for other rod sizes, is shown in Fig. 7. Aside from its general utility, an interesting fact to be derived from this graph is that, for a given current, the larger rod sizes burn off considerably less metal than the smaller rod sizes. This is shown in Table 8.

Table 8—Rate of Rod Burnoff with Rod Size

Rod diameter, in.	Burnoff rate
At 350 amp.	
$^3/_{64}$ in., lb. per hour	14.0
$^3/_{32}$ in., lb. per hour	9.7
% increase for $^3/_{64}$ in. over $^3/_{32}$ in.	45

However, for a given welding application, less penetration will be secured with a larger rod, and it will, therefore, be used at a somewhat higher current which in turn will raise the deposition rate close to the value obtained with the smaller rods.

Comparison—Sigma Welding and Hand Flux-Coated Welding

The burnoff rate for hand flux-coated metal arc welding is also essentially the same as it is for sigma welding at a given current. For instance, on page 238 of the 1950 *Welding Handbook*, at a current of 200 amp., 5.5 lb. per hour of electrode is burned off. For sigma welding employing a $^1/_{16}$-in. electrode at 200 amp., 6 lb. per hour are consumed. At 250 amp., the comparison is 7.2 lb. per hour for hand welding, and 7.8 lb. per hour for sigma welding. However, there are two distinct differences in considering the burnoff rate of sigma welding and that of hand flux-coated arc welding:

1. On the average only about 60% of the weight of the electrode is deposited as filler metal in the case of flux-coated electrode; whereas with sigma welding approximately 98% of the electrode is deposited as filler metal.

2. In general, higher currents may be employed with the sigma process.

The rod burnoff and metal deposition rates for flux-coated electrode welding with standard and hot rod techniques and sigma data for welding under comparable conditions are given in Table 9.

Table 9—Rod Burnoff and Metal Deposition Rates—Flux-Coated Electrode Welding vs. Sigma Welding

	Flux-coated electrode		*Sigma welding*	
	Standard	*Hot rod*	*Low current*	*High current*
Rod diam., in.	$^5/_{16}$	$^1/_4$	$^3/_{32}$	$^1/_{32}$
Current, amp.	250	400	350	500
Rod burnoff rate, lb. per hour	7.2	13.6	9.7	15.5
Deposition efficiency, %	60	61	98	98
Deposition rate, lb. per hour	4.3	8.4	9.5	15.2

The minimum usable current for any given rod size will be that current at which the drop transfer rate becomes so low that excessive spatter occurs. This

occurs at a point where the drops are just barely visible. The maximum usable welding current is not limited by technical considerations, except that high current densities produce more porosity. However, the largest usable rod size is recommended to take advantage of the lower cost of the large diameter rods. The suggested current ranges are shown in Table 1.

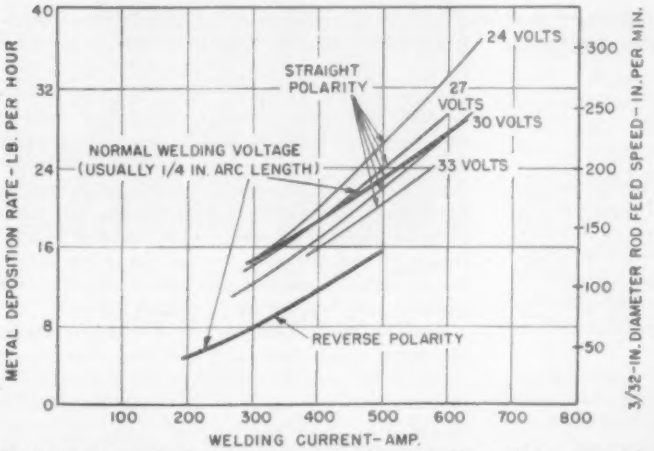

Fig. 8 The effect of voltage on burnoff rate using straight polarity current in sigma welding

Straight Polarity

Figure 8 illustrates the effect of voltage on burnoff rate using straight polarity current. Also included is a curve representing a normal welding voltage for the various currents. For comparison, a similar curve for reverse polarity is also shown. An inspection of the graph will show that at a welding current of 400 amp. the burnoff rate is 17.5 lb. per hour, while with reverse polarity it is 11.5 lb. per hour. Expressed as percentage, the straight polarity arc burns off 50% more metal than the reverse polarity arc at a current value of 400 amp.

IX. SAFETY PRECAUTIONS

Sigma welding and the flux-coated electrode welding processes both involve open electric arcs. Generally, the standard safety precautions and procedures established for flux-coated electrode welding should be carefully observed in sigma welding operations. The amount of spatter is less with the latter than with the former, and less hazard exists from this factor. On the other hand, due to the absence of dense smoke with sigma welding, the intensity of radiation is slightly higher.

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(*Continued on page 1097*)

Powder Washing for Metal Removal

An improved method of removing excess or defective material from castings. Apparatus and techniques are described

by R. S. Babcock

POWDER washing has been developed to meet the requirements of the steel-foundry industry for an improved method of removing excess or defective material from castings. This process is now considered to be a practical foundry tool as the result of close cooperation with several steel foundries where experimental apparatus was field-tested under production conditions.

Production of steel castings includes a considerable amount of clean-up work after the castings are removed from the molds. In the average steel foundry, more than one-third of the metal poured is excess metal in the form of risers, gates and fins. This excess metal is removed from a casting on the cleaning floor.

Removal of excess metal has been accomplished by oxygen cutting, chipping and grinding. Chipping has been generally used for rough cleaning and for light-metal removal. Grinding has been used for finish cleaning and produces smooth surfaces free from projecting ridges.

Oxygen cutting has been used until recently principally for rough cleaning, such as cutting off risers and gouging out defects. Oxygen cutting is quiet and much less fatiguing than chipping or grinding since no operator pressure is required on the tool. Oxygen cutting is also much faster than chipping or grinding, but the surface finish has generally not been considered accurate or smooth enough for finish cleaning, except in a few cases where mechanized cutting has been used for the removal of gates and risers. Because of the many advantages that oxygen cutting possesses, various means of improving the process for foundry work were investigated. The result of this continued study has been the development of the new technique called "washing."

A washing technique with standard oxygen-cutting equipment was considered a few years ago as a possible means of supplementing or replacing the slower chipping and grinding processes without sacrificing surface quality. Sufficiently encouraging results were obtained with the preliminary washing apparatus to warrant adoption of the process by a few steel foundries. However, it was apparent that further improvements in speed and control would be necessary before the process could be generally adopted for average steel foundry cleaning floor operations. The addition of iron powder to the oxidation reaction appeared to offer the best means of further improving the washing process.

While the powder processes were developed originally for cutting, gouging and scarfing stainless steels, it was subsequently found that burning iron powder particles transmit heat more rapidly than gas flames. This characteristic is particularly suitable in cases where heat transfer from the preheat flames is the limiting factor in promoting combustion of the base material. For example, in cutting steel castings with adhering sand or sand inclusions, the addition of powder to the cutting process permits a continuous oxidation reaction and produces more uniform cut surfaces. This led to the combination of powder and oxygen-gouging equipment for washing out sand inclusions, scabs or penetrations, and burned core sand. The same equipment, when applied to the removal of excess metal from steel castings, speeded up the process and permitted the close process control that was desired.

APPARATUS

Early powder-washing operations were carried out with standard (internal powder feed) powder apparatus such as that used in gouging stainless steel. Fig. 1 illustrates the use of this equipment in removing fused sand and penetrations from the fillets of a large crosshead casting.

Later, special equipment was developed using a combination of a hand-blowpipe and a powder attachment (external powder feed), as shown in Fig. 2. This blowpipe is characterized by its straight head, rugged construction, high preheat capacity and a sensitive oxygen valve which provides for improved operator control over the oxygen flow rate.

Washing nozzles have been made for both oxyacetylene and other oxy-fuel gas mixtures. They incorporate high preheat capacity and a low-velocity oxygen stream.

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Fig. 1 Fused sand and penetration from the fillets of a large cross-head casting are being removed by powder-washing. The blowpipe, normally used for flame-gouging of stainless steel, has internal powder feed

vibratory powder dispensers are available. These latter dispensers contain electrical vibrator units and suitable controls for accurate adjustments. The powder itself is an iron-rich powder of uniform particle size and possessing good flow characteristics. The powder, marketed as Oxweld No. 200 cutting and scarfing powder, is packaged with a drying agent in airtight metal containers.

APPLICATIONS

Washing equipment may be used for removing fins which occur at the parting line between sections of the mold. These fins consist of thin sections of metal ranging from a fraction of an inch to several inches in height, and $^1/_{16}$ to $^1/_4$ in. in thickness. The base of the fin is blended with a slight radius to the adjoining surfaces of the casting itself. A typical light fin is illustrated in Fig. 3 (*a*). Frequently mold sand adheres to the metal at the base of these fins. While the thin edge of the fin can be brought up to ignition temperature very rapidly by the preheat flame of a cutting, gouging or scarfing nozzle, the presence of sand insulates the underlying material and prevents continuation of the oxidation reactions. Some of this sand is so firmly bonded to the surface of the steel that the oxygen stream tends to gouge into the adjoining casting surfaces when the standard cutting nozzle is held long enough in one spot to melt away the adhering sand. The surface left after washing a clean fin from a casting by means of a washing

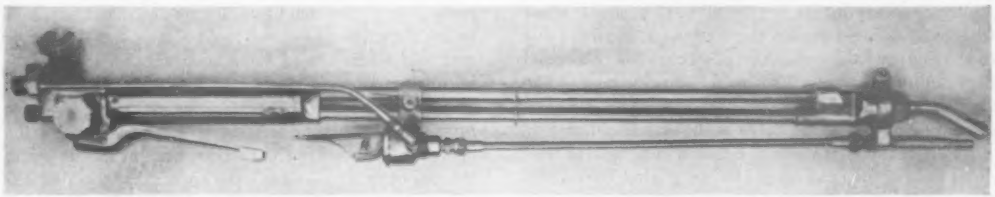

Fig. 2 This blowpipe, with external powder feed, was developed specially for powder-washing operations

The latter is accomplished by including a metering orifice in the oxygen passage.

The powder attachment consists of a slotted powder nozzle with a clamping bracket by which it is attached to the blowpipe head. The powder nozzle is made of stainless steel lined with a heavy copper sleeve and is so designed that it can be easily cleaned or replaced. The powder flow is controlled by the powder valve which is mounted on the blowpipe tubes adjacent to the blowpipe handle. Since the washing blowpipe may be used either with or without the powder attachment, the latter is attachable rather than incorporated as a permanent part of the blowpipe. The powder is fed to the blowpipe attachment through a section of welding hose similar to that used for the oxygen and preheat gas. The powder is conveyed in a stream of compressed air with which it is mixed at a controllable rate as the airborne powder leaves the powder dispenser.

Several different powder dispensers are available ranging from a small portable pneumatic type, holding approximately 30 lb. of powder, to a larger model holding up to 200 lb. of powder. For more critical operations, where precision powder feed is desired,

Fig. 3 (a) A typical light fin is illustrated here

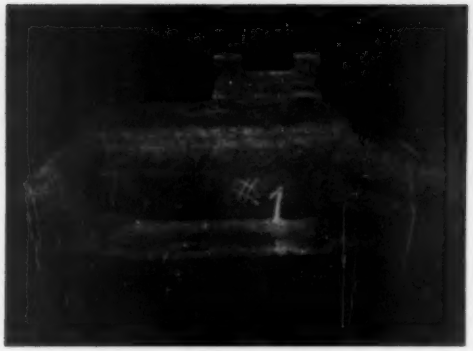

Fig. 3 (b) Flame-washing, without powder, has left this clean surface

Fig. 3 (c) This is the surface left by chipping a similar fin

nozzle without powder is shown in Fig. 3 (*b*). The surface left by chipping a similar fin is represented in Fig. 3 (*c*).

The washing blowpipe with powder attachment provides a means of removing the fin and adhering sand, and permits an operator to blend in the casting surfaces on either side of the fin location. In cases where multiple-section molds are employed, a slight offset frequently occurs between the sections of the mold due to shifting, and these shifts or offsets are easily blended to a uniform contour by the washing process. The fin-washing technique consists of moving the flame in an oscillating motion as indicated in the sketch of Fig. 4.

In the removal of pads, the action is similar to that described for the removal of fins except that the oscillations are longer, to cover the greater width of the pads. In pad removal, the washing blowpipe is usually operated at a slower rate of forward progression as this depends upon the width and height of metal which must be removed. The average operator can easily remove riser pads by the powder-washing process and blend the pad surfaces to the contour of the casting so that it is difficult to detect where the risers were previously attached.

Removal of sand inclusions is an operation which is very well suited to the powder process. Sand inclusions in castings occur as the result of loose sand which is washed away from the mold surface during a pour either by the movement of the metal or by the blast of escaping gases generated in the mold. The sand particles are then contained in the steel casting as it solidifies, frequently leaving a hard, spongy appearing surface, and must be removed before the casting can be considered sound. Removal by chipping is rather slow because the cutting edge of the chisel is rapidly dulled as it contacts the hard mass imbedded in the steel; this leads to frequent changing or resharpening of chisels. Grinding is also slow and progressively more and more difficult with increasing depths of sand below the surface of the casting.

Both chipping and grinding tend to draw adjacent metal over the defects and thereby conceal remaining portions of these defects from visual inspection. The oxygen-gouging process is well suited for removing defects in steel castings by attacking the metal adjacent to the defect in a localized rapid combustion. Defects such as sand inclusions, being noncombustible, show up in the reaction as spots of different light intensity. This characteristic makes gouging a highly desirable process for removing defects in steel castings as the operator can observe the reaction zone at all times and it is unnecessary to remove the apparatus to inspect the area as is the case in chipping or grinding.

The increased preheat capacity of the washing blowpipe and nozzles permits faster rates of defect removal, and the addition of powder not only provides instantaneous starts, but also supplies a superheated molten

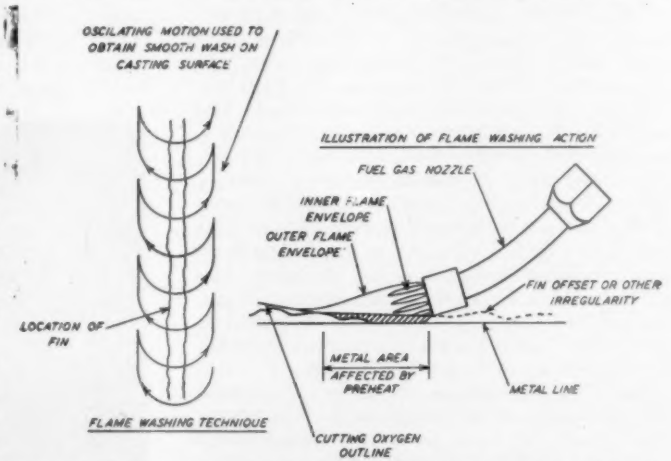
OSCILATING MOTION USED TO OBTAIN SMOOTH WASH ON CASTING SURFACE
LOCATION OF FIN
FLAME WASHING TECHNIQUE
ILLUSTRATION OF FLAME WASHING ACTION
FUEL GAS NOZZLE
INNER FLAME ENVELOPE
OUTER FLAME ENVELOPE
FIN OFFSET OR OTHER IRREGULARITY
METAL AREA AFFECTED BY PREHEAT
METAL LINE
CUTTING OXYGEN OUTLINE

Fig. 4 The technique of moving the flame in an oscillating motion for fin-washing is indicated

iron oxide which attacks and floats out the sand particles. The combination of the burning iron powder and sand produces specks of higher light intensity in the surface of the oxygen-steel reaction zone. These specks are easily distinguishable to the operator and are used as a guide in establishing the rate of progression. The light spots disappear from the reaction surface as soon as the reaction reaches solid metal.

Penetrations are another source of trouble in cleaning room operations. A penetration occurs as a lump having a rough surface on the outside of a casting and is composed of sand particles in a matrix of steel. It results from a breakdown of the sand mold surface which permits the molten steel to penetrate between grains of sand before solidification. These bulges were previously removed by chipping or grinding, depending upon their location and size. Such operations were very slow, laborious and costly. Extensive penetrations occasionally indicated scrapping and recasting as the only economical solution. The powder-washing process is well suited for the removal of penetrations for the same reasons that it is effective in the removal of adhering sand or sand inclusions. A light penetration is being removed in the fillet area between the boss and outside of the bearing-cap casting in Fig. 5. The curved in powder-washing reaction zone closely approached the radius of the fillet so that a single progressive pass cleaned the casting completely in this area.

Burned core sand presents another cleaning problem in steel foundries. If a core fuses to the casting surface, or is permeated by metal or oxide, it is very difficult to remove, not only because of its hardness, but also because the cores are generally located on inner or more inaccessible parts of the casting. The powder-washing reaction rapidly removes burned core sand so that the casting can be cleaned in a fraction of the time normally required for the removal of this type of defect by other methods.

In steel foundries chill rods and bars, reinforcing nails, and core chaplets are auxiliary items that must be removed from castings during the cleaning operations. The rods and bars are imbedded below the mold surface to chill the metal and thus prevent cracking which often develops while the solidifying metal has insufficient skin strength. They are generally employed along fillets and similar critical sections. Rods and bars are usually removed by rapping with a cleaning bar, but occasionally the location may prevent ready access of such a tool. In such cases the washing blowpipe can be effectively used to separate the chill pieces from the casting without danger of damaging the casting.

The nails and chaplets are imbedded in the mold surface to reinforce the sand or support cores, and thus portions of them become firmly imbedded in the casting. Their shanks or extending sections may be removed by chipping at a fairly rapid rate. However, the powder-washing process enables the operator to remove the excess portions of these items as rapidly as he can position the nozzle. As previously indicated, the velocity of the oxygen stream is so regulated that there is no tendency for these small reaction zones to spread from the nails and chaplets to the adjoining or underlying base metal of the casting. This is partially due to the oxidation-resistant skin of the casting itself. Nails and bonded sand are being removed by the powder-washing blowpipe in Fig. 6. In this case a uniform layer of sand was washed away, exposing the casting surface in a progressive sideward movement such as used in washing pads. In Fig. 7 chaplets and heavy nail stubs are being washed away.

Occasionally cracks or tears occur during solidification and cooling of steel castings. Although alterations in casting or molding practice may prevent the recurrence of such defects in subsequent castings of similar design, it is also necessary to remove the cracks as they show up in castings on the cleaning floor. Light sur-

Fig. 5 A light penetration is being removed in the fillet area between the boss and outside of the bearing-cap casting

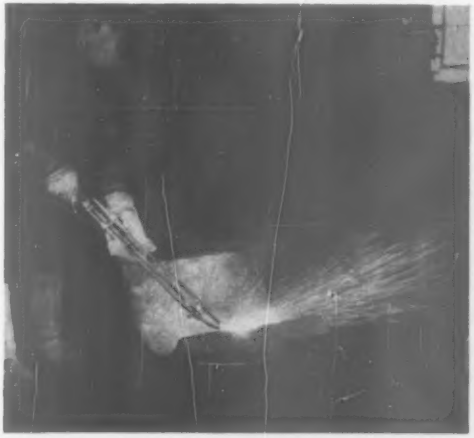

Fig. 6 The powder-washing blowpipe is being used to remove nails and bonded sand

Fig. 7 Chaplets and heavy nail stubs are being washed away

face cracks can be removed by grinding or by use of a gouging chisel. However, unless the crack follows a fairly straight line, it is difficult to follow the changes in direction with either of these methods and there is also the tendency to draw adjacent metal over narrow cracks so that under visual inspection they appear to be completely removed. With the oxygen-gouging process, it is easy for the operator to see the crack to its full extent and to follow the direction of the crack with the reaction zone. The powder-washing process enables the operator to start the reaction rapidly and to follow the crack to its full depth regardless of the distance below the casting surface, since the reaction is effective 2 in. or more away from the nozzle.

Repair welds are made whenever it is necessary to fill in voids created in cleaning out defects extending below the casting surface. In making these repair welds, scale and electrode coatings float out and adhere to the top surface of the weld. It is normal practice to build up the repair weld to a level above the casting surface so that the surface irregularities of the weld metal and flux can be removed by chipping or grinding down to the casting surface. Repair weld reinforcement can be removed by the washing process. Such operations cost less than half of the previous grinding and chipping costs. The powder-washing process provides an excellent means of removing surface and composition irregularities and of blending the weld metal to the surface of the casting.

WASHING TECHNIQUES

Washing techniques for removal of fins and of weld reinforcement are very similar. The nozzle is held at approximately a 45-degree angle and oscillated slowly to provide an overlap of about one-half inch on either side of the excess metal. The burning iron powder forms such an effective heating medium that the reaction is continuous as the blowpipe is oscillated from side to side. It may be necessary to concentrate the reaction or make a preliminary pass to remove some excess metal. The average operator can remove metal up to $^1/_4$ in. above the casting surface and blend the washing surface into the casting surface very rapidly. The removal of chills merely requires the application of the blowpipe in such a manner that the reaction started on the surface of the chill continues until all of the chill metal has been consumed or cleared from the casting. Pads and penetrations may require more than one pass to completely remove the excess material. Pads up to 4 in. wide can be removed in a single pass by moving the blowpipe from side to side across the material. Pads over 4 in. wide will require additional passes in multiples of 4-in. widths. Each pass is blended to the preceding pass by overlapping so that a uniform surface is produced. The before and after views in Fig. 8 show a Diesel engine truck casting completely cleaned by the washing process. The removal of cracks and sand inclusions follows the standard gouging technique which is greatly stabilized by the addition of burning powder.

Powder washing as a means of metal removal has proved to be a very satisfactory process and should be

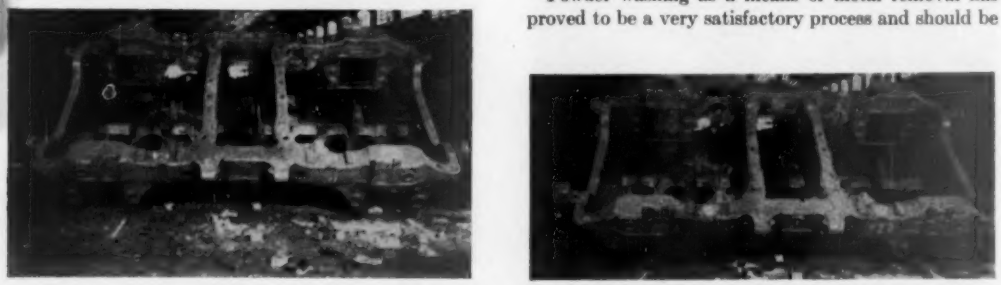

Fig. 8 Truck casting before and after washing

advantageous to any steel foundry where the above described defects are encountered. Powder washing may be applied to any carbon or alloy-steel castings under the same conditions that apply for cutting or welding. Powder washing is most important as a means of eliminating bottlenecks which occur on the cleaning floor. The process is particularly adaptable to large castings which require mechanical assistance in moving and/or which require an appreciable amount of metal removal.

The powder-washing technique is easily mastered in a short time. The operation of the blowpipe is substantially the same as that of other oxyacetylene cutting or gouging apparatus. The powder apparatus has been proved dependable and as trouble-free as other cutting and welding equipment when operated under recommended conditions. There is no toxic effect resulting from the burning powder fumes or smoke. Normal ventilation is recommended for average working conditions. Operators find adequate protection in ordinary working clothes with suitable heat-resistant gloves or mittens and a face shield with medium dark lens. Protective clothing may be desirable in working on alloy materials at elevated temperatures.

FIELD EXPERIENCE

Perhaps the most successful introduction of the powder process was encountered in one steel foundry where the work was allocated to one of the finish grinders who was well acquainted with the finish requirements on the various castings. Although this man was unfamiliar with oxyacetylene equipment, he picked up the process technique in less than one hour's time and turned out finished products at a much faster rate than previously. The experience of this foundry with powder washing is typical of the results that can be obtained with the process. A heavy mining machine casting which formerly required 1 hr. of grinding was cleaned by powder washing in less than five minutes. Another casting which formerly required 4 to 6 hr. of grinding is now washed in approximately one hour. The increased production and reduction in cost of labor and overhead more than make up for the cost of gases and powder consumed.

Another foundry uses the process only for removing sand penetrations and burned cores. In one application at this foundry, a layer of sand up to $^1/_2$ in. thick was washed from the inside of a 12-in. inside diameter, 6-ft.-long hydraulic cylinder in less than two hours. This was outstanding in view of the fact that there was no other way of removing the sand at the center of this cylinder with available tools.

Large turbine housings with several hundred pounds of penetration have been cleaned up with the powder-washing process in a matter of a few hours, whereas previously—with only chipping and grinding—it would have been uneconomical to reclaim these castings except by scraping and recasting.

Another foundry had several wheel-type castings with burned sand located between the spokes and web in deposits 8 in. deep and approximately 8 in. across. After spending approximately a week of chipping at the deposits on one side of a wheel with heavy pneumatic chipping tools, the equivalent deposits on the opposite side were cleaned out with powder washing in a matter of $2\,^1/_2$ hr.

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(*Continued from page 1091*)

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Dilution and Diffusion Aspects of Nonfusion Welding

Science of physicochemical phenomena and thermodynamic data applied to a better understanding of the brazing processes

by R. D. Wasserman and J. Quaas

NONFUSION welding is defined as the bond between the brazing metal and the base metal and is obtained by a diffusion of the filler metal into the base material and by surface alloying of the base metal and the filler material.

Heretofore, formulae for brazing and soldering filler metals have been developed by empirical methods, but we now have a much more scientific approach by applying physicochemical and thermodynamic data to dilution and diffusion phenomena. The object of this paper is to show some of the observations and findings which have been made concerning the phenomena which occur in conventional brazing and soldering and concepts which have been resolved and which lead to new alloys with improved properties.

One of the most common methods for nonfusion welding of ferrous materials is the use of alpha or beta brass as the filler metal. This process permits low-heat joining with a minimum of warping and overheating. If two sections of mild steel are brazed together using an alpha brass alloyed with nickel as the filler metal and then a tensile specimen is prepared to judge the tensile strength of the joint, our specimen would show a tensile strength of 100,000 lb. per inch^2 which is superior to that of mild-steel parent metal. The ultimate strength obtained depends on the gap distance originally employed in setting up the two sections of mild steel which were to be brazed. The same test can be made using silver solder as the filler metal. If the gap between the joined members is 0.003 in. or less, the strength of the bond is improved and this strength is greater than that of the component parts of the joint. In either case, we have found that the iron of the parent metal had diffused into and/or diluted the filler metal, thereby changing its physical properties.

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A new brazing alloy for stainless steel consisting of a nickel-chromium-boron-iron base that is applied at a temperature of approximately 2000° F. is interesting in that after brazing its melting point is increased considerably, due to boron diffusing into and/or diluting with the parent metal. Thus the bond itself has very different characteristics than either the original parent metal or the filler metal.

The welding of cast iron with a mild-steel electrode provides another example of the phenomena which we are discussing. The carbon of the cast iron is diluted with and diffuses into the mild-steel filler metal, forming a series of alloys with varying carbon contents. Each alloy has its own heat expansion characteristics during cooling and hence the weld results in a poor weldment with numerous microcracks. Thus, the carbon movement between the adjacent material is an essential problem which must be considered in brazing and welding cast iron.

In nonfusion welding, the heated base metal comes in contact with the molten filler metal and dilution occurs to some extent. If dilution can be minimized, as is preferred in all nonfusion welding applications, then diffusion plays a more important part in creating the bond. Diffusion is more desirable since dilution tends to form brittle compounds resulting in bonds of poor strength. For example, if a phosphorus-copper filler material were applied on steel or iron and much dilution occurred, the bond would exhibit low physical properties due to the formation of brittle iron phosphides.

In order to decide the correct filler metal to be used on various base materials, definite fundamental rules must be followed to obtain optimum results. The problem of dilution is first treated experimentally using phase diagrams with which we are all familiar and other thermodynamic principles. The Hume-Rothery law is then applied to our particular problem. This law is of utmost importance and states qualitatively that substitutional alloy can only be formed on a large scale providing the atomic radii are approximately the same size. Figure 1 shows, graphically, the atomic radii of metallic atoms expressed in Angstrom units. The difference in size of the atomic radii is called atomic size factor and if the atomic size factor exceeds 15%, then the intermixture is unfavorable and very restricted. When applying the Hume-Rothery law to a particular problem, we encounter many obstacles. When an element goes into solution the atomic size varies. Also, electrovalency has its effect.

The tendency to form a compound or intermediate compound proceeds at the expense of the primer solution. The more electropositive the solvent and the more electronegative the solute, the easier it is to form a compound. Therefore, alloy systems composed of bismuth, arsenic, antimony and phosphorus with copper or silver have a size factor that appears to be favorable but solid solutions of these metals are restricted, because compounds are formed which are very stable. The Hume-Rothery law, then, while one of our best guides for depicting formation of solid solution alloys is similar to other empirical laws in that many other factors must be resolved before our findings are correct and successful.

Diffusion in nonfusion welding is still more complex and much more important to us than the dilution problem. The greater the diffusibility at the same temperature, the better is a particular alloy suited for joining at lower heat. Diffusion is an atomic movement or migration of the atoms through the solid parent metal under the influence of heat. It is a relaxation phenomenon which proceeds to equalize the concentration differences between the filler and base materials. If we bring a piece of pure copper in intimate contact with zinc at 700° F. these metals will form a series of layers of alpha, beta, delta, sigma and epsilon phases and we will find that the atoms of zinc migrate deeper into the copper than copper into zinc as was proved by Masing and Spring in 1909.

In order to deduce some important rules to be followed to properly interpret what governs diffusion, we must apply fundamental laws covering these phenomenon

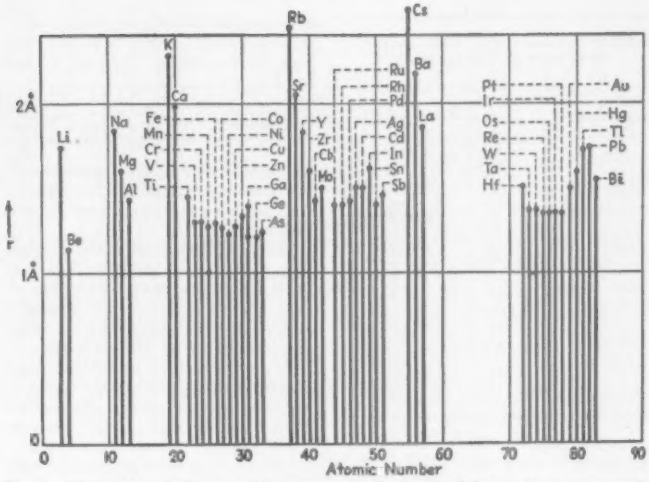

Fig. 1 The radii of the metallic atoms as determined from the interatomic distance

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in much the same manner in which we approached the dilution aspect. The first formal law of diffusion was given by Fick in 1855. This law states that the amount of a substance dm moving in x direction in time dt across an area A is proportional to the concentration gradient dc/dx in the plane of the area A and is equal to:

$$dm = -DA \frac{dc}{dx} dt \qquad (1)$$

This equation means that the concentration is dependent on time and location or distance as shown in the formula assuming D to be constant. The derivation of Fick's second law is given in the mathematical appendix of this report, as is also a particular solution of the Fick equation.

Graphically, the picture of diffusion can readily be seen as shown by Fig. 3. This graph is in accordance with Fick's second law and in its construction the diffusion constant D was given the value 2.5×10^{-7} cm.^{2} sec.$^{-1}$.

To further present the picture of diffusion Table 1 shows various values of D as reported by R. Mehl for copper as a base metal with aluminum, tin and zinc as additives. Iron as a base metal is also shown with aluminum and tin as the diffusion metals. It will be noticed that D is not constant as was supposed in the Fick formula but is affected by temperature, as well as by concentration.

Much effort has been spent attempting to fix a definite relation between D and various atomic constants but always contradictions occur which prevent the formulation of simple rules. The only general rule which we can apply to diffusion is that two metals with a greater relative distance in the periodic table will provide greater diffusibility. Like most general rules, this one also has its exceptions in that electrovalency must be taken into consideration. In Fig. 4 using silver as the base material we can see that our general rule holds except in the cases of palladium and antimony. This graph indicates that with increased atomic number the diffusion constant is likewise increased except in cases where electrovalency has its effect.

Along with the laws of Fick and various solutions of the Fick formulae another helpful tool to those concerned with the complexities of metallic diffusion is a half-empirical formula divulged by Dushman and Langmuir. Before exploring this

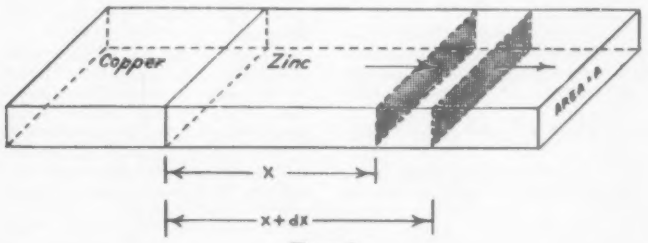


Figure 2

Graphically, Fig. 2 depicts the essentials of this equation. D in this formula is the diffusion constant and represents the amount of material diffusing in unit time across unit area A when the concentration is unity. The negative sign is required in the formula since diffusion is opposite to the greater concentration. The diffusion constant D is the factor with which we are concerned and its derivation will be the motive in our discussion.

A second law of Fick which is derived from the first law eliminates the difficult-to-measure m of the equation and is expressed as the following partial differential equation:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \qquad (2)$$

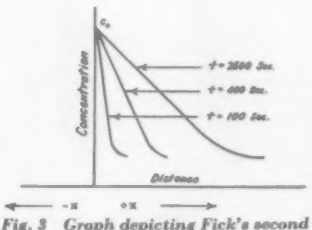


Fig. 3 Graph depicting Fick's second law. Diffusion constant D was evaluated at 2.5×10^{-7}/cm.^{2} sec.$^{-1}$

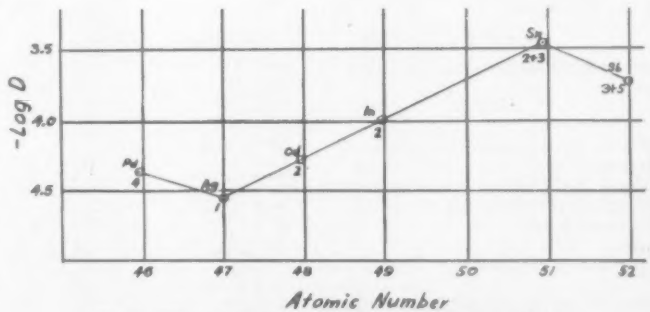


Fig. 4 Effect of electro-valency on the diffusion constant

formula and its possibilities, let us investigate further the theory that diffusion is an atomic movement. In solids, diffusion can be conceived in three ways, namely:

1. Interstitial diffusion.
2. Vacancy diffusion.
3. Substitutional diffusion.

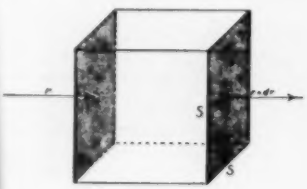
Interstitual diffusion occurs when a foreign atom moves between the basic material lattice such as takes place when carbon diffuses into gamma iron.

Vacancy diffusion occurs when a foreign atom moves into existent vacant sites in the lattice of a crystal.

Substitutional diffusion occurs when two atoms in a lattice are loosened and are forced to interchange their respective positions. Substitutional diffusion should be considered a self-duffusion process in which, for example, copper atoms are diffused with isotope copper atoms.

Having established the theory that diffusion is an atomic movement which can occur in various ways, let us consider a cube of metal in which the distance between two atomic planes in the direction of diffusion is S and the probability that an atom moves from one plane to the other in a second is d. If n_1 is the number of diffusing atoms per unit area and n_2 represents the same occurrence in the other plane, then the number of atoms passing from one plane to the other in unit time can be expressed as follows:

$$\frac{dN}{dt} = d(n_1 - n_2) \qquad (3)$$



Volume = $S^2\,dr$
Figure 5

From Fig. 5 it is evident that the volume V can be shown as

$$V = S^2\,dr \qquad (4)$$

and by substitution of formulas 3 and 4

$$\frac{dN}{dt} = dS^2\,dr \qquad (5)$$

If $n_1 - n_2$ is proportional with V which we have shown to be equal to $S^2\,dr$ and considering that the diffusion constant D is the number of atoms in unit time moving in r direction then:

$$\frac{dN}{dt} = D\,dr = dS^2\,dr \text{ and } D = dS^2 \qquad (6)$$

Thus, we can see that the diffusion constant can be expressed as the probability that one atom moves in one second times the square of the atomic distance. This supposition has been proved to be of general value only.

Table 1—Values of Diffusion Constant D as Reported by R. Mehl

Metal combination	*Temperature, ° C.*	*Diffusion constant, $cm.^2\,t^{-1}$*
Cu-Al	500	1.5×10^{-7}
	650	3.0×10^{-6}
	850	1.9×10^{-4}
Cu-Sn	400	4.1×10^{-8}
	500	5.8×10^{-7}
	650	6.0×10^{-6}
	760	1.2×10^{-4}
Cu-Zn	360	8.3×10^{-8}
	500	6.8×10^{-7}
	650	4.9×10^{-6}
	880	4.8×10^{-4}
Fe-Al	900	33.0
	1150	170.0
Fe-Sn	950	8.4
	1000	17.2
	1050	34.0
	1100	66.0

Prior to interpreting the Langmuir-Dushman equation previously mentioned we must first consider D to be a function of temperature. Empirically this can be expressed as follows:

$$D = D_0 e^{-Q/RT} \qquad (7)$$

D_0 and Q are characteristics for every metal combination, T is the absolute temperature in degrees Kelvin and R is the gas constant 2 cal./mol. The Langmuir-Dushman equation states:

$$D_0 = \frac{Q}{Nh} S^2 \qquad (8)$$

N in this formula denotes Planck's constant of 6.6×10^{-27} ergs and h denotes the Loshmidt number. Combining equations 7 and 8:

$$D = \frac{Q}{Nh} S^2 \nu e^{-Q/RT} \qquad (9)$$

Q in this formula is known as the dislocation or activation heat which is necessary to loosen the atom in its lattice. It is interesting that its value is less than the heat of evaporation. For lead, for example:

Heat of melting, cal./gm. atom.... 1,100
Dislocation heat, cal./gm. atom.... 27,900
Evaporation heat, cal./gm. atom... 36,200

This heat of activation can be determined by measuring D, the diffusion constant, for a single concentration at various temperatures.

The values of D_0 and Q are the main factors concerning diffusibility and both quantities can be measured experimentally. We might construe D_0 as being a measure of the movability of the atoms and Q as the amount of work required to loosen an atom from its crystal lattice. The larger the value of Q, the smaller is the diffusibility in an exponential way due to its negative sign in the equation. Table 2 depicts values for Q which were calculated from the Langmuir-Dushman equation and others which were ascertained experimentally.

Like so many other tools the Langmuir-Dushman formula is not accurate if the activation energy is small or if diffusion occurs at the grain boundaries. The value of the formula is qualitative because it suggests Q is independent, but in reality Q is a function of concentration as well as temperature. Figure 6 shows results obtained using copper as a base metal and zinc, aluminum, beryllium, cadmium and silicon as the diffusing material. It can be seen that as the concentration varies aluminum has a greater diffusion coefficient than zinc, but at some concentration the zinc might have a larger constant than aluminum.

The various types of diffusion complicate and make difficult an easy-to-resolve picture concerning these phenomena. Not only does lattice diffusion occur during brazing, but we must conceive of grain boundary and surface diffusion taking place. All these types have different Q activation values. Listed

Table 2—Values of Q Derived from the Langmuir-Dushman Equation and Experiments

Alloy system	*D_0 value*	*Q in cal./atom, experimental*	*Q in cal./atom, calculated*
Au in Pb	4.9×10^{-1}	13,000	13,300
Ag in Pb	7.5×10^{-2}	15,200	15,700
Bi in Pb	7.7×10^{-3}	18,600	21,900
Cd in Pb	2.1×10^{-2}	18,000	20,000
Zn (9.58%) in Cu	3.2×10^{-2}	42,000	41,000
Sn (10%) in Cu	...	40,000	38,000
Cu in Ag	5.9×10^{-6}	24,800	...
Sn in Ag	7.9×10^{-6}	21,000	...
Bi in Bi $\perp$ C	1.16×10^{-4}	145,000	...
Bi in Bi $\parallel$ C	2.2×10^{-4}	30,000	...
Zn in Cu	8.0×10^{-1}	38,000	44,000
Mg in Al	1.5×10^{2}	38,500	29,000
Mo in Wo	5.0×10^{-3}	80,500	...
C in Fe	4.9×10^{-1}	36,600	36,700
N_2 in Fe	1.17×10^{-1}	34,000	38,100
U in Wo	1.0×10^{1}	100,000	100,500

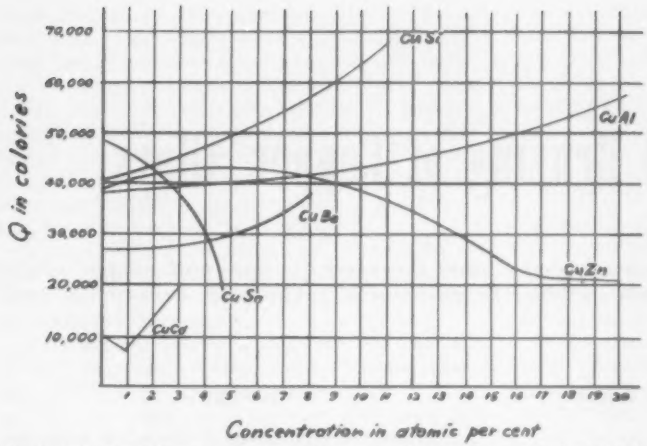


Fig. 6 Relation between Q values and concentration for Cu-Al, Cu-Be, Cu-Cd, Cu-Si, Cu-Sn and Cu-Zn systems

below are D and Q values for the self-diffusion of silver:

D lattice = 0.089 Q lattice = 49,950 cal./gm. atom
D grain boundary = 0.025 Q grain boundary = 20,200 cal./gm. atom
D surface = 0.16 Q surface = 10,300 cal./gm. atom

These values show that surface diffusion is the greatest and can be made with the lowest heat and heat energy.

The wetting action of a filler alloy is related to surface diffusion and at the same temperature the diffusion along the surface might be several times greater than diffusion into the metal crystal itself.

In a copper-nickel system copper will diffuse deeper into the nickel than nickel into copper at the same temperature. The same is the case of brass and iron where the iron has considerable effect in raising the strength of the brass. As mentioned previously, the gap dimension has its effect on mutual diffusion, as was illustrated in the case of silver brazing. The degree of surface wetting of brazing alloys is also explained in many ways by surface diffusion.

Much work remains to be accomplished in respect to diffusibility in the field of nonfusion welding alloys. We have tried to present the relationship between the atomic distance and the diffusion constant but no general rule seems applicable in all cases. With more complicated systems than we have mentioned in this paper, the resolvement of diffusion phenomena would be even more complex. We can see, then, the vast field which lies ahead for researchers in this interesting work.

Mathematical Appendix

Derivation of Fick's second law

Referring to Fig. 2, at a distance x, the amount of material diffusing through the cross-sectional area A is:

$$dm_x = -DA \left(\frac{dc}{dx}\right)_x dt \quad (1)$$

and at the distance $(x + dx)$,

$$dm_{x+dx} = -DA \left(\frac{dc}{dx}\right)_{x+dx} dt \quad (2)$$

By subtraction, formulas 2 from 1, the amount of diffused material in the length dx is:

$$dm_{x+dx} - dm_x = + DA\, dt \left[\left(\frac{dc}{dx}\right)_{x+dx} - \left(\frac{dc}{dx}\right)_x\right] \quad (3)$$

To further evaluate the difference shown in the brackets of the above equation we have:

$$\left(\frac{\partial c}{\partial x}\right)_{x+dx} - \left(\frac{\partial c}{\partial x}\right)_x = \frac{\partial^2 c}{\partial x^2} \quad (4)$$

Therefore,

$$dm_{x+dx} - dm_x = DA\, dt \left(\frac{\partial^2 c}{\partial x^2}\right) dt \quad (5)$$

and the amount of diffused material in the differential volume $A\,dx$ or dv is equal to:

$$\frac{dm_{x+dx} - dm_x}{dv} = \text{concentration } c \quad (6)$$

Thus, considering all factors, Fick's second law is expressed:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \quad (7)$$

A particular solution of the Fick equation is as follows, assuming the concentration c_0 is held constant at a distance x_0:

$$c = \frac{c_0}{2}\left(1 - \frac{2}{\sqrt{\pi}} \int_0^y e^{-y^2}\, dy\right) \quad (8)$$

where $y = x/2\sqrt{DT}$.

This formula provides a method for calculating the concentration at any time and distance. The following, part of the particular solution shown above, is called the Gauss error function and is found accordingly:

$$\Phi(y) = \frac{2}{\sqrt{\pi}} \int_0^y e^{-y^2}\, dy = 1 - \frac{2c}{c_0} \quad (9)$$

Tables for the Gauss-error-function values are available and hence the concentration can be evaluated as a function of distance and time. Its value varies between 0 and 1 as y varies from 0 to infinity.

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The Welding and Brazing of Copper Alloys

A survey of the more important copper and copper alloys and the welding processes and techniques commonly used

by J. Imperati and Ira T. Hook

INTRODUCTION

STARTING as sheets, tubes, rods, wires, extruded or rolled shapes, and forgings and castings, copper and the copper alloys are manufactured into a wide variety of products. These are often joined by a welding or brazing process as well as by soft soldering or mechanical fastenings. For the most part, we are concerned here only with wrought copper and copper alloys, though much of the data would also apply to the thousands of copper, brass, and bronze castings. As is indicated by the title, we shall direct attention principally to the welding and brazing processes.

The Base Metals. Copper and its alloys constitute such a wide variety of metals with such markedly different properties and characteristics that it is necessary to separate them into eight different groups and consider joining procedures for each individual group. These eight groups are listed in Table 1.

These alloys are in great demand in peace or war because of their excellent combination of properties. These include, in copper or one of its alloys, such desirable qualities as.

(*a*) High electrical and thermal conductivities.
(*b*) Excellent resistance to corrosion in the atmosphere, in fresh, brackish, or sea water, and in many chemical solutions.
(*c*) Good strength, even at low temperatures.
(*d*) Excellent wear resistance and machinability.
(*e*) Desirable aesthetic properties.
(*f*) Good soldering, brazing, and welding properties.

The last-named properties are the ones with which we are chiefly concerned at the moment and which we shall consider in some detail below.

J. Imperati, Welding Engineer, and Ira T. Hook, Research Engineer, both of the American Brass Co., Waterbury, Conn.

This paper was presented at the 12th Annual Ohio State Welding Engineering Conference.

SOLDERING

We need dwell but briefly on the soft soldering and the silver brazing processes as they apply to copper.

Table 1

Group no.	*Composition, %*	*Name, remarks, and A.S.T.M. Specifications*
1	99.9+ copper	(*a*) Tough pitch copper. Carries 0.02 to 0.07% of oxygen in form of microscopically small specks of cuprous oxide. A.S.T.M. B152, Types ETP and FRTP (*b*) Deoxidized or oxygen-free copper. Has no cuprous oxide in it. Phosphorus deoxidized copper has 0.015 to 0.040% residual phosphorus. A.S.T.M. B152, Type DHP
2	95 to 80 copper 5 to 20 zinc	Commercial bronze and red brass. Special alloys may contain lead for free machining or tin for improved strength and resilience. A.S.T.M. B36
3	75 to 58 copper 25 to 42 zinc 0 to 1 tin	Spring brass, cartridge brass, common brass, Muntz metal. An addition of 0.5 to 1.0% tin is found in Tobin Bronze. Fractional per cents of tin, iron and manganese will be found in manganese bronze. 2 to 3% of lead is generally found in extruded architectural bronze and brass forgings. A.S.T.M. B36 and Navy 46B6
4	72 to 55 copper 10 to 32 zinc 10 to 20 nickel	Wrought nickel silver usually has 18 to 25% nickel with 20 to 25% zinc. Extruded nickel silver is higher in zinc, about 40%, and lower in nickel, 10 to 12% with 2 to 3% lead. A.S.T.M. B122
5	90 to 70 copper 10 to 30 nickel	Cupronickels. A.S.T.M. B122 and Navy 46C6
6	96.5 to 89 copper 3.5 to 11 zinc 0.03 to 0.35 phosphorus	Tin bronze or phosphor bronze. Grade A phosphor bronze has 4 to 5% tin, Grade C about 8% tin and Grade D about 10.5% tin. A.S.T.M. B103
7	98 to 95 copper 1.5 to 3.5 silicon 0.50 to 1.5 manganese, zinc, or tin	Everdur, copper-silicon alloys. A.S.T.M. B96
8	96 to 88 copper 4 to 9.0 aluminum 0 to 3.5 iron	Aluminum bronze, forging bronze and Avialite bronze. Frequently contains about 1% of iron, manganese and/or nickel. A.S.T.M. B169

These processes are well understood. They are, however, of major importance in the electrical, the sheet metal, and the plumbing industries and a short discussion is quite apropos for the sake of completeness.

Soft solders, including the usual 50:50 lead-tin solders and the 95 tin – 5 antimony solder are readily applied to all of the alloys in Groups 1 to 6 inclusive, using a zinc chloride flux and any convenient method of heating that will bring the work up to the 300 to 450° F. melting temperature of the solder.

In many electrical connections a noncorroding flux is required. Powdered rosin and rosin dissolved in alcohol or as a core in the solder wire is the most satisfactory flux for this purpose.

In the soft soldering of the copper-silicon alloys of Group 7, care must be exercised to clean the base metal thoroughly and cover it with flux before the heat is applied. The solder must be flowed into place as soon as the base metal approaches the fusion temperature of the solder. For this reason, a powdered solder mixed with flux may be preferred. If the base metal is heated without a protective layer of flux, a thin, invisible film of oxide develops and interferes with the bonding of the solder.

The aluminum bronzes of Group 8 are even more difficult to soft solder on account of the invisible coating of oxide which forms on the surfaces. No practical way has been discovered for soft soldering the aluminum bronzes.

SILVER BRAZING

All of the copper alloys in Groups 1 to 7, inclusive, are readily brazed with the usual borax base fluxes and silver brazing alloys at temperatures between 1175 and 1500° F. The aluminum bronzes of Group 8 may also be silver brazed, though a flux with a generous addition of a fluoride is required.

A group of brazing alloys, made up of copper and about 5% of phosphorus (some of them also containing silver), is sometimes used on the tough pitch and deoxidized coppers of Group 1 at a temperature around 1300° F. No flux is required as the phosphorus content of the solder acts in lieu thereof. These alloys are not often used for joining the metals in Groups 2 to 8, inclusive.

BRAZING AND BRAZE WELDING

From the glossary of the AMERICAN WELDING SOCIETY we learn that in these processes the metals are joined by heating them to at least 800° F. and flowing into or onto the joint a nonferrous filler metal having a melting point below that of the base metals.

Since we have already covered silver-alloy brazing, we shall limit the rest of this discussion to those processes carried out at temperatures between 1550 and 1725° F., which use the copper-alloy brazing metals to join the metals of Table 1 without fusion of the latter. Representative brazing alloys are listed in Table 2.

General Remarks on Brazing

In the case of the soft solders and the silver-brazing processes, the solder is always melted and drawn in between contacting surfaces by capillary attraction. The same is true of the spelter solders of Table 2. In such applications the strength of the connection, as well as its pressure tightness, depends almost entirely upon the resistance of the solder to shearing stress.

In many applications where one of the three welding rods of Table 2 is used, the molten bronze may be drawn into the overlapping surfaces of the joint by capillary attraction as is done with a soft solder or silver solder. Such use of the filler bronze in developing shear stress resistance is desirable for economical use of the brazing metal.

However, the tensile strength of the three bronze welding rods of 40,000 to 70,000 psi. in the as-welded

Table 2—Representative Copper-Alloy Brazing Metals*

Mark or name	*Melting temp., ° F.*	*Approx. compn., %*	*Remarks*
Spelter solders	1620	50 copper 50 zinc†	Yellow bronze in lump, granulated or finely powdered form
Naval brass, Tobin bronze, etc.	1625	57 copper 0.50 tin Remainder zinc	Free-flowing yellow-bronze welding rod
Manganese and low-fuming bronzes‡	1600	56 copper 0.85 tin plus iron, silicon, manganese Remainder zinc	Low-fuming yellow-bronze welding rod
Nickel bronze	1690	48 copper 10 nickel 0.10 silicon Trace of phosphorus Remainder zinc	Low-fuming, high-strength, white-bronze welding rod

* Other copper alloys which melt at higher temperatures are also used for brazing, e.g., pure copper melting at 1981° F. and cupronickels at still higher temperatures. These, however, are used on ferrous metals and are unsuited for use on the copper-alloy base metals of Table 1.

† Part of the copper or zinc may be replaced by tin to reduce the melting point to 1495° F., or by nickel to obtain a white metal.

‡ A small fractional percentage of silicon in the welding rod helps to keep down the zinc vapor. Hence, the name "low-fuming" for such rods.

conditions is such that an open V-weld may be and usually is employed, for deoxidized copper and the brasses. Such use, formerly known as bronze welding is now called "braze-welding" to connote the combination of a V-weld joint made as a braze, i.e., without fusing the base metal.

With the reinforcement left on it is easy to develop the full strength of the annealed base metal. However, this application is not suitable for the copper-silicon and the aluminum-bronze alloys because of low bond strength.

Brazing vs. Silver-Alloy Brazing and Soft Soldering

In settling a question as to whether to use one or the other of these joining methods, a number of effects must be considered before the brazing metal and exact procedure can be specified.

Service Temperature. A joint made with soft solder cannot be subjected to anything but very moderate operating temperatures. If the joint is a seal only, it can withstand a higher temperature than if it is to take stress at elevated temperature but generally a soft soldered joint should not be subjected to temperatures above 220° F. The strength of soft solder drops off rapidly as the temperature is raised. In this respect the 95 tin–5 antimony solder is to be preferred to the 50 tin–50 lead solder as it retains a much better proportion of its normal strength at the temperature of boiling water than do the lead-tin solders.

Soft-soldered joints for hot- and cold-water lines in domestic plumbing are generally satisfactory and have good durability. They are the only joining materials applicable at a sufficiently low temperature to retain the cold work temper of hard-drawn copper tubes. Silver-alloy brazed joints will soften the hard-drawn copper tube to an appreciable extent and brazing at temperatures above 1600° F. will make the copper tube dead soft at the joint.

Joints exposed to coal, gas or oil flames should be silver-alloy brazed or bronze welded.

Brazing Procedure

All of the metals of Table 1 may be brazed with the welding rods of Table 2, with the following exceptions and precautions:

The aluminum bronzes of Group 8 are not commonly brazed, partly because of the difficulty of fluxing the oxide skin and partly because they are used for special purposes involving their nonscaling and corrosion-resisting properties, and their strength and hardness, which the yellow welding bronzes would not match to the desired degree. The Group 8 metals are more properly fusion welded or silver-alloy brazed.

The metals of Group 3, such as Muntz Metal, Naval brass, extruded architectural bronze and manganese bronze, are not brazed in the usual sense as there is no practical difference between the fusion temperature of base metal and welding rod. (See discussion on welding.)

The other base metals of groups 1 through 7 can be readily brazed.

Leaded brasses require special care in brazing operations on account of the sweating out of the lead at temperatures well below the brazing temperature. The lead oxidizes but the oxide at brazing temperature is not stable and is apt to dross the weld metal unless fluxed out with a good brazing flux. In oxyacetylene heating a slightly oxidizing flame is useful because it helps to stabilize the lead oxide.

Welding of Copper Alloys

All of the copper alloys are weldable in one way or another. We are concerned, therefore, in choosing the optimum welding procedure for the particular alloy group and for the particular service the welded metals

Table 3—Copper Alloy Welding Rods

Name (Proposed A.W.S. class)	*Composition, %*					
	Copper, min.	*Zinc*	*Tin*	*Silicon*	*Manganese*	*Phosphorus*
Copper (R Cu)	98	...	0.0–1.0	0.0–0.5	0.0–0.5	0.0–0.15
Copper-silicon (R Cu Si)	94	0.0–1.5	0.0–1.5	2.8–4.0	0.0–1.5	...
Cupronickel (R Cu Ni)	67	Nickel 29.0–33.0	...	0.0–0.5	0.25	...
Phosphorus bronze A (R Cu Sn-A)	94	Zinc ...	4.0–6.0	...	...	0.1–0.3
Phosphorus bronze D (R Cu Sn-D)	88.5	...	9.0–11.0	...	...	0.1–0.3
Naval brass (R Cu Zn-A)	57	Remainder	0.5–1.0	...	...	...
Manganese bronze (R Cu Zn-B)	56	Remainder	0.5–1.0	...	0.01–1.0	Iron 0.5–1.0
Low-fuming bronze (R Cu Zn-C)	56	Remainder	0.5–1.1	0.10–0.25	0.01–1.0	0.5–1.0
Nickel bronze (R Cu Zn-D)	45	Remainder	Nickel 9.0–11.0	0.10–0.25	...	...
Aluminum bronze (R Cu Al-A)	87.5	Aluminum 9.0–11.0	...	...	...	1.5

are to encounter in further processing or in their end use. We will consider them in their respective groups. The copper and copper-alloy welding rods available for these applications are listed in Table 3.

Group 1, Coppers

Two grades of copper are shown because, while both can be welded, only the deoxidized copper will produce efficient joints. The reason for this is briefly as follows. Tough pitch copper has scattered throughout its structure many minute particles of copper oxide which do not reduce the physical and electrical properties of the wrought metal. However, at temperatures above 1300° F. this oxide migrates and collects at the grain boundaries and weakens the copper. In addition, if hydrogen is present, as during oxyacetylene welding, it diffuses into the copper and reduces the oxide at the grain boundaries. The result is the production of water vapor or steam which disrupts the copper internally and causes further weakening. The weakening effect is a function of temperature and time. It is present even in brazing operations but its effect is less noticeable because of the large shear areas usually provided in bronzed joints.

Deoxidized copper is free of oxide and the residual phosphorus insures against the production of oxides during brazing and welding operations. There can thus be no weakening from this source. Therefore, deoxidized copper is always recommended for all brazed and welded fabrication.

The welding methods commonly used now are (*a*) oxyacetylene and (*b*) inert-gas-shielded metal-arc welding. The oxyacetylene method affords good control and has been widely used even for vertical welding. The shielded tungsten arc method, like other arc welding methods, is usually limited to downhand welding.

A variety of copper filler rods are available, such as (*1*) a plain phosphorus deoxidized copper, (2) a 1% silver-bearing copper, (3) an alloy with about 0.25% of silicon, and several combinations of these. Only those with silicon added can be expected to develop fairly good strengths in the joints as welded and without subsequent hammering. The others can develop strengths ranging up to about 25,000 psi. and are not entirely free of porosity.

To date the best results have been obtained with a patented alloy containing nominally 98.85% copper, plus small additions of tin, silicon and manganese. Welds made with this alloy consistently develop the full strength of annealed copper and maximum ductility in reduced-section tensile tests. Welds made with it readily meet the requirements of the A.S.M.E. Code for Unfired Pressure Vessels for which copper has been approved, namely, Paragraphs U-69 and U-70.

The carbon-arc method has often been used in the past to join copper and it offered the advantages of fairly good speed and control. Unfortunately, copper rods could not produce sound high-strength weld metal with it and the method was limited to those cases where a phosphor bronze or a copper-silicon alloy filler rod could be used. The advent of the inert-gas-shielded-arc method removed the necessity for further work with the carbon arc.

The metal-arc method has not been used extensively (even though many flux-coated electrodes with copper and copper alloy core wires have been advanced for the purpose). The chief difficulty has been the high heat conductivity of copper which has required extensive preheating of the work in order to obtain good fusion. Also, the current densities required in the electrodes have resulted in excessive spatter loss and poor control.

To recapitulate, the present preferred method for welding copper is the inert-gas-shielded tungsten-arc method using a filler rod of substantially pure copper deoxidized and strengthened with tin, silicon and manganese. In addition, the newly developed inert-gas-shielded automatic metal-arc methods (Aircomatic and Sigma) have been successfully used for deoxidized copper, and here also the best results have been achieved with a copper filler wire like the one described above. The indications are that this method may eventually supplant most of the others in the fabrication of copper pressure vessels and process equipment.

Group 2, Low-Zinc Alloys

These alloys cannot be successfully fusion welded with filler metals of the same compositions, because of excessive porosity and resulting low strength. Some success can be achieved for architectural purposes by using filler metal strips cut from the base metal and the oxyacetylene method. Porosity will be kept to a minimum by using a very oxidizing flame adjustment and keeping the flame cone $^1/_8$-in. or so away from the work. Arc welding has only occasionally been used and then has been limited to the carbon-arc method with filler rods of phosphor-bronze or copper-silicon alloy.

Group 3, High-Zinc Alloys

These alloys are readily fusion welded with the oxyacetylene method and filler rods of the low-fuming manganese-bronze type. This type of rod assures the production of welds with minimum porosity and maximum strength and ductility. The procedure has been used successfully for making pressure vessels of Naval brass, for instance the heat exchangers in some of the fresh-water units built for the armed forces in World War II.

The carbon-arc method can be applied if necessity requires it, but the tremendous volume of zinc smoke produced militates against it.

The flux-coated electrodes of 10% aluminum bronze have quite often been used for welding these high-zinc alloys, particularly in reclaiming worn and defective castings. They may require some preheat in the base

metal in order to reduce the current densities and thus keep spatter loss to a minimum.

The advent of the new inert-gas-shielded automatic metal-arc method has opened new possibilities in the fabrication of pressure vessels of these alloys. As indicated in the paper presented by Messrs. Robinson and Berryman at the 1950 Metal Congress, these high-zinc alloy base metals can be successfully and efficiently welded with an aluminum-bronze filler wire. The method is now being used for the repair of eroded propeller blades in marine service.

Group 4, Nickel-Silvers

These alloys are used principally for flat ware for silver plating, and soft soldering is usually employed. There are also some applications for architectural purposes and here silver-alloy brazing is usually employed. Fusion welding is seldom required which is fortunate because of the poor results obtained with it.

Group 5, Cupronickels

These alloys have been widely used in marine applications such as for condenser tubes, evaporators, salt-water lines, etc., because of their excellent corrosion resistance. They are suitable also for many other applications because of their good ductility at low temperatures. The most commonly used alloy has been the 70–30 version, but a new alloy with only 10% nickel plus 0.75% of iron will probably be more widely used now in the effort to conserve nickel.

The 70–30 alloy has been most successfully welded with the metal-arc method. Flux-coated electrodes are available from several sources and welders have been qualified to handle these electrodes in all-position welding as required by Navy Dept. Specification 46E5. These electrodes develop the full strength of the annealed base metal without difficulty and can also be used to weld the new 10% nickel alloy. In addition, a well-known maker of flux-coated electrodes has developed a satisfactory electrode for the new 10% nickel alloy.

The 70–30 alloy may also be welded using the oxyacetylene method and a filler rod carrying a small amount of silicon. Welds so made have easily developed the minimum specified annealed strength of the wrought base metal.

The carbon-arc method is not suitable for the cupronickels and is not recommended.

In inert-gas-shielded arc welding, both the tungsten-arc and the automatic metal-arc versions are being studied and it seems quite likely that suitable filler metal compositions will be developed in the near future.

Group 6, Phosphor Bronzes

The Grade A alloy, containing 4 or 5% tin, is the one most widely used for the fabrication of pressure vessels and chemical equipment. Such fabrication has been done successfully with the flux-coated electrodes which have been available from several makers. In general, these electrodes have been suitable only for downhand welding, and to secure maximum control with minimum spatter it has been necessary to preheat the base metal to about 600° F. It has been possible to develop practically the full strength of the annealed plate 45,000 psi. or better, with properly trained operators.

This alloy has also been welded with the carbon-arc method and bare filler rods of similar composition. While control has been somewhat easier, welding is still limited to the downhand position. More important, it has not been possible to develop more than 75% of the annealed base-metal strength.

The inert-gas-shielded tungsten-arc method has also been applied to these alloys with moderate success. Weld metal porosity results in lowered strength and ductility. Maximum results will probably require the use of special filler-rod alloys which are not available at present.

The inert-gas-shielded automatic metal-arc methods are now being studied for use with the phosphor bronzes. The results to date indicate that they can be joined successfully with filler wires of the same compositions as the base metals.

The oxyacetylene method is not satisfactory because it produces excessive weld-metal porosity.

Group 7, Copper-Silicon Alloys

Of the copper alloys this group is probably the most widely used for pressure vessels and chemical equipment. Its fabricating properties and corrosion resistance have led it to be adopted for the majority of domestic hot-water tanks, for gasoline tanks, liquid-air storage tanks, brew kettles, evaporators, condensers and a large variety of other process equipment. It is weldable by all the methods commonly used.

Probably the most frequently used today is the inert-gas-shielded tungsten-arc method with either argon or helium for the shielding gas, and usually with direct current. The maximum results available in strength, ductility and soundness are consistently obtained and the joints easily meet all the requirements of the A.S.M.E. Code for Unfired Pressure Vessels. Distortion is kept to a minimum with the added advantage that no flux is used and there is no slag-removal problem. The filler metal is the same composition as the base metal.

The inert-gas-shielded metal-arc method also gives exceptionally good results and in addition permits higher speeds and all-position welding.

The oxyacetylene method was formerly widely used where maximum ductility and soundness were required along with good strength. It probably has been completely supplanted by the above-mentioned methods.

The carbon-arc method has in the past been most widely and successfully used for pressure vessels made

to the requirements of Paragraphs U-69 and U-70 of the A.S.M.E. Code. It is still useful for many applications and is, of course, easier to use and less expensive than the other methods.

The metal-arc method with flux-coated electrodes has not been widely used because of the lack of electrodes capable of depositing high-quality weld metal.

Group 8, Aluminum Bronzes

These alloys have always been exceptionally difficult to weld because of the heavy refractory oxides which form on the heated metal. Very active fluxes, usually high in fluoride content, are needed to prevent interference from these oxides. Flux-coated electrodes have been developed and it is possible with them to achieve satisfactory results with the metal-arc method. As is well known, there are several compositions available, and those with aluminum contents up to 10% are commonly employed for the wrought plate materials that are available. The electrodes with higher aluminum content are used for overlaying die and bearing surfaces where higher hardness is required.

Flux-coated rods in the same grades as the electrodes are also made for use with the carbon-arc method. The remarks just made apply here also.

The inert-gas-shielded automatic metal-arc method is now being applied with remarkable success to these alloys. It promises to increase extensively the field of application for them.

The inert-gas-shielded tungsten-arc method has not yet been found suitable for welding these alloys due to interference from heavy slag on the weld metal. This slag forms whether the power source is a. c. or d. c. and with both argon and helium.

The oxyacetylene method cannot be used on the aluminum bronzes.

RESISTANCE WELDING

This paper would not be complete without a few words about the resistance welding of the copper alloys. Although it probably is not a matter of common knowledge many articles made of copper alloys, ranging from jewelry and hardware to small pressure vessels and refrigerator evaporators, are regularly fabricated by resistance-welding methods. In general, for resistance spot and seam welding, the weldability of the alloys varies inversely as their electrical and thermal conductivities. Thus, copper is virtually unweldable, while the copper-silicon alloys and the cupronickels are the most weldable.

Experience has shown that maximum strength in spot and seam welds can be achieved consistently with the following conditions:

1. Uniformly clean surfaces.
2. Electrode pressures somewhat lighter than for steel.
3. Short welding times with maximum of 6 to 8 cycles.
4. High welding currents, ranging from 150 to 300% of those required for steel of comparable thicknesses.

As stated above, copper is practically unweldable. The low-zinc alloys of Group 2 are only slightly less difficult to weld and it is not advisable to attempt to make anything but spot welds and then only where moderate strengths are desired. In order to develop maximum strengths and make pressure-tight seam welds it is necessary to use the special red brasses that have been developed for the purpose. These alloys usually contain about 1% of silicon or 1% of manganese, and are used for making domestic refrigerator evaporator shells and the cold-wall assemblies for larger refrigerator installations.

The weldability increases somewhat as the zinc content increases but even so the ordinary yellow brasses and the manganese, Tobin and Naval brasses of Group 3 are suitable only for spot welding. Where pressure-tight seam welds are to be made the welding must be done on the special silicon-bearing alloys developed for the purpose.

The addition of nickel to make the nickel silvers of Group 4 increases the weldability still further. The straight cupronickels of Group 5 are also fairly weldable. Successful work can be done with these two groups of alloys following the suggestions made above and using current values about 50% higher than for steel of the same thicknesses.

The phosphor bronzes of Group 6 are rather difficult to weld because of the ease with which they stick to the electrode faces. This is a result of the fluxing action of their phosphorus content and is the reason they seldom are welded by resistance methods.

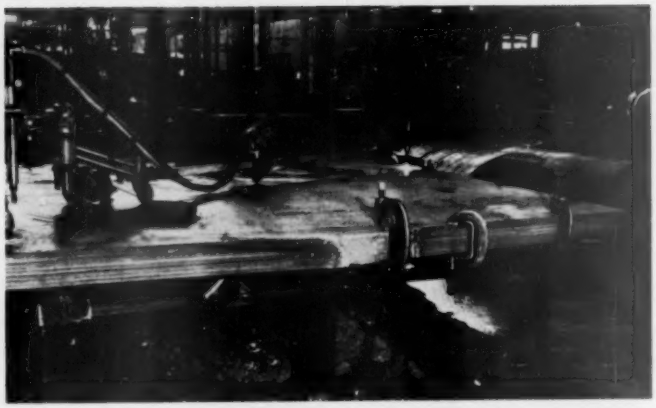
The copper-silicon alloys of Group 7 are the most weldable of all and naturally have been widely used for all sorts of resistance welding. Current requirements are only 25 to 50% above those for steel of the same thickness.

The aluminum bronzes of Group 8, especially those with 5 and 8% aluminum, are rated as moderately weldable. With the conditions stated above current requirements are about 50% higher than for comparable thicknesses of steel.

PRACTICAL WELDER AND DESIGNER

Eight 12-ft. Diameter Circular Tank Heads Flame-Cut Simultaneously to Proper Size in Minimum Time

HERE is an unusual flame-cutting machine setup that makes it possible to cut as many as eight 12-ft. diameter tank-head blanks at the same time. The time required to cut the blanks for dished heads from stacks of eight $^3/_4$-in. thick steel plates has been halved by using two cutting blowpipes at opposite ends of the boom. The actual speed of both blowpipes is 5 in. per minute. An Oxweld CM-16 portable cutting machine has been equipped with a heavy arm and pivot point. The hose block in the center is mounted on a swivel to prevent the hose from being twisted. This installation was made at General-American Transportation Corp., Sharon, Pa.



Merry-Go-Round Cutting Jig

STRAIGHT-LINE cuts in any direction, without moving the part being cut, are possible with a circular cutting jig designed by a Missouri welding shop for oxyacetylene cutting. An Oxweld CM-16 cutting machine is mounted on the jig which can be moved manually through 360 degrees to follow any straight-line cutting pattern.

A sturdy angle iron table is the base for the jig. A circular steel band, approximately 5 ft. in diameter is bolted to the top of this base. Riding on this band, by means of a series of rollers, is a second steel band. A round bar railing is attached to this second band for about a third of its circumference. This railing supports one end of the track on which the cutting machine rides. The track just rests on the railing, and the operator can slide the track end along the railing. The other end of the track is attached to a swivel joint on the revolving steel band. The operator moves around the part being cut, and by turning the steel band or sliding the track on the railing he positions the cutting machine.

The C. E. Cummings Co. of La Due, Mo., who designed the jig, claims that it works well on many cutting jobs. It is particularly useful, they say, for working with heavy steel plate that would be difficult to move into position under the cutting machine for each cut.

Fig. 1 This circular cutting jig is used in cutting intricate straight-line patterns from steel plate. The jig can be revolved so that a cut can be made in any direction, without moving the part being cut. For further flexibility, the track on which the CM-16 cutting machine rides is fixed to a swivel joint at one end and the operator can slide the other end of the track along the railing beneath his left hand

Fabricating Aluminum

DESIGN and development engineers responsible for the economical production of defense orders are accumulating swipe files of ideas they can adopt from all manner of industry. Here are two neat tricks pertinent to the fabrication of aluminum, which well may serve such purposes. They were done by ingenious workmen in the building trades in that recent era during which there was aluminum for everybody. They come from the files of All-State Welding Alloys Co., Inc., 273 Ferris Ave., White Plains, N. Y.

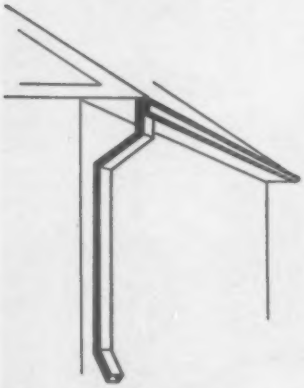


Fig. 1 Roofers in certain areas were reluctant to use aluminum gutters and downspouts because soldering, as they were accustomed to soldering, would break with expansion. Their problems were solved by brazing with an especially developed aluminum brazing alloy, which gave a tensile strength of 30,000 psi. and which is as easy to apply as solder

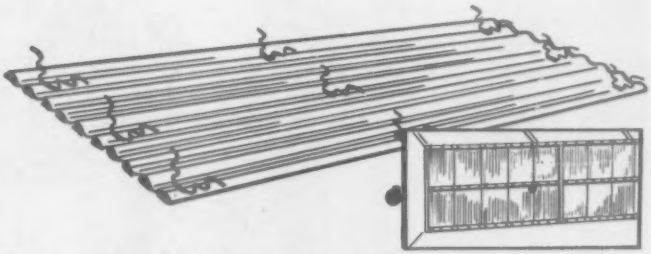


Fig. 2 Corrugated aluminum for the sides and roofs of portable buildings was made completely reclaimable by substituting wire ties for nails. Short pieces of $^{3}/_{16}$-in. diameter All-State X-2S aluminum wire were brazed on the underside of the sheet at the places where nailing would ordinarily be required. Tying these wires to the framing eliminated nailing. Brazing was done quickly and economically, without burn-throughs, with special brazing alloys and techniques that were unavailable during World War II

A Large Sand Loader

A MACHINE shop recently built the large capacity sand elevator illustrated.

The 43-ft. long loader is framed of 8-in. gas pipe and is equipped with 50 rollers. The belting is made of 2-ft. wide rubber which carries sand to a height of about 17 ft. to be loaded on railroad cars at a speed of 100 ft. a minute.

The supporting elements were $2^{1}/_{2}$-in. pipes welded and hinged on the axle and are raised and lowered by a cable and windlass. The hopper is framed with angle iron and covered with 10-gage sheet metal.

The elevator is driven from the bottom by a Model T rear axle gear, a shaft running lengthwise to a bended gear at the top.

The elevator will carry $2^{1}/_{2}$ tons of gravel per minute.

In the fabrication of this elevator 100 lbs. of Airco No. 90 Electrode were used.

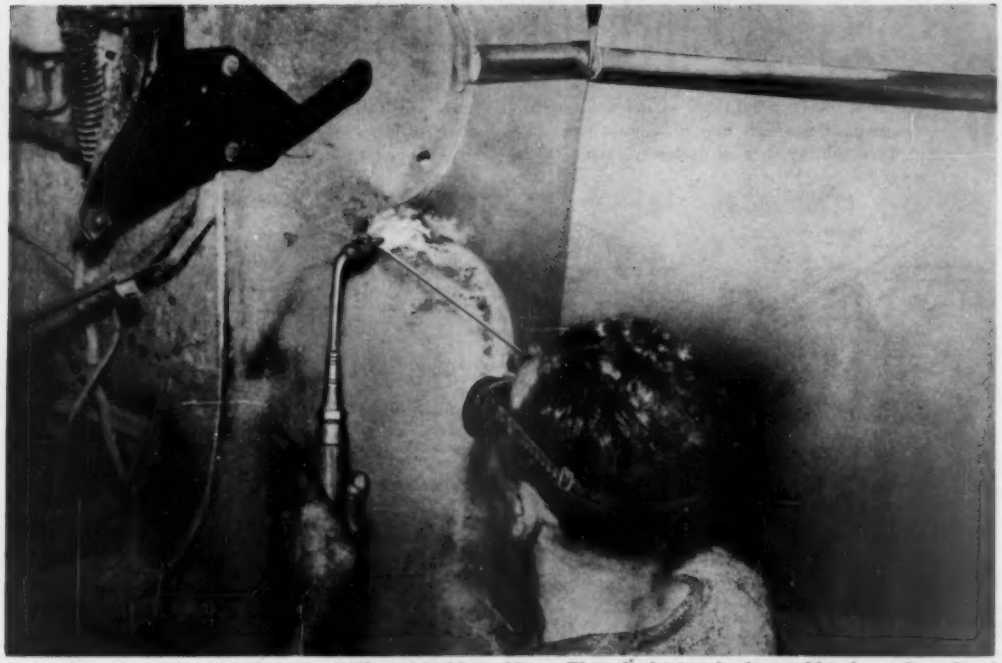


Fig. 3 Several tears in the body were quickly repaired by welding. Then the fairing, fenders and hood were heated and straightened. Dents and low spots in the fenders and hood were filled with body solder

Body and Fender Shop "Magic"

Badly smashed front end made to look like new

by C. Hopkins

MAGIC seems like the right word when you compare Figs. 1 and 6. Yes, it's the same car. Only the radiator and grill of the car in Fig. 6 are new. Fortunately, the motor was still in good condition when the automobile was brought into the body and fender shop. The car was made to look like new—thanks to the oxyacetylene flame, which was used for heating, welding and soldering.

First the fenders and fairings, hood, radiator and grill were removed. Then body tears were welded and bent or dented parts were heated and straightened. Body solder was applied to build up low spots and make a smooth surface. The welding blowpipe again supplied the heat. Parts damaged beyond repair were replaced,

Fig. 1 Here is how the car looked when it came into the shop. The first step was to remove the fenders and fairings, the hood, radiator and grill

C. Hopkins is connected with the Linde Air Products Co., a division of Union Carbide and Carbon Corp., San Francisco, Calif.

Fig. 2 Here is the car after damaged parts were removed. Only the radiator and grill could not be salvaged. Except for a few scratches, the motor was undamaged

Fig. 4 The fairing was set in place and both fenders attached. Then a new radiator was bolted in place. Here the operator is fitting the left fairing to the body. Note the body solder on the left fender

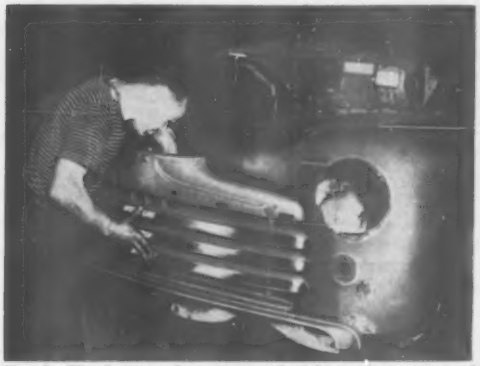


Fig. 5 The front end was sprayed with a priming coat of paint, then a new grill and a new windshield were added

Fig. 6 Repair "magic." Here is the car after repairs and a new finish. It looks and operates like new

and after a repaint job, the car looked and operated like new.

Photographs: Courtesy of Duco-Dulux Refinisher.

Flame Cutting Stud Shields

HEAVY steel stud shields are being fabricated on this jig with an Oxweld CM-16 cutting machine. The shields, made from steel pipe, are placed over studs sunk in concrete floors to protect the stud threads while heavy pieces of machinery are being lowered onto the studs. Four cuts are made in each piece of pipe on this jig. The pipe is turned by the operator after each cut is completed. The cut sections of pipe are then heated and shaped, like the shaped sections at the left of the jig. The cuts are then welded, and the shield interior partially threaded. The E. T. Hazeldine Machine Co. of Terre Haute, Ind., is making these shields for defense plants in which difficulty has been experienced in installing heavy machinery. Before the shields were designed many studs had been damaged and much time lost while the damaged studs were ripped out of their concrete bases and replaced.

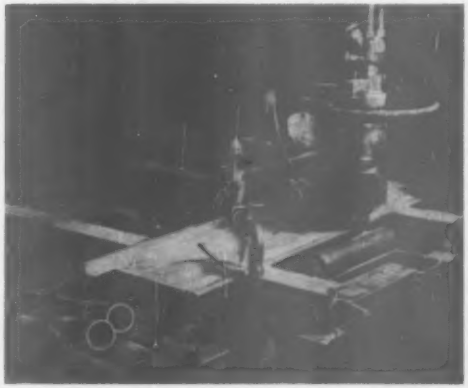


Figure 1

Clamp for Pipe Welding

by M. D. E. Robinson

WHEN working with pipe, it is frequently desirable to have some form of clamp for holding sections of pipe. Many types of clamp can be made. Some are clamped over the pipe end; others require temporary welds. Here is a clamp which is inexpensive, easy to make and easy to attach. Fig. 2 gives dimensions for making clamps suitable for most sizes of pipe.

M. D. E. Robinson is connected with the Dominion Oxygen Co., Ltd., Vancouver, B. C., Canada.

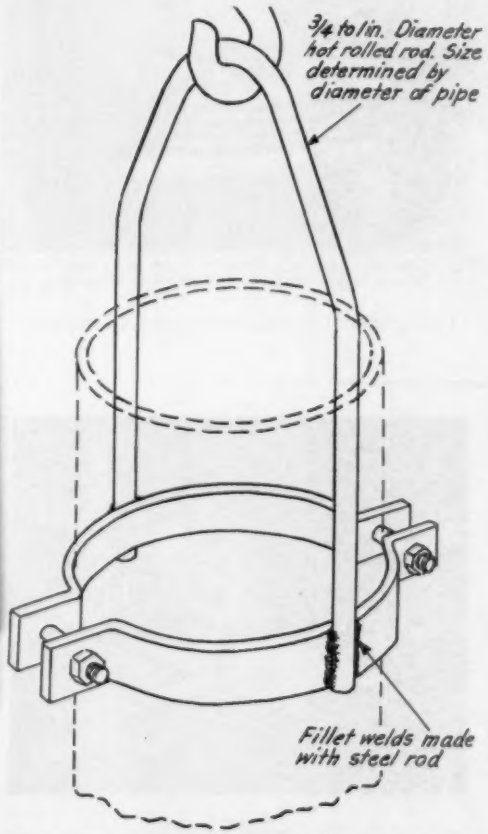


Fig. 1 This type of clamp will be found satisfactory for practically all pipe-handling applications. It can be made in a short time from scrap material

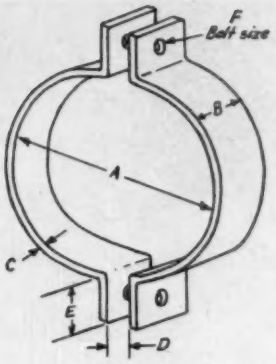


Fig. 2 Dimensions for making the clamp are shown here

Size of pipe, in.	Diameter, in., A	Length, of bar, in., L	Width of bar, in., B	Thickness of bar, in., C	Space between ears, in., D	Length of ear, in., E	Bolt size, in., F
3	3.50	9	1 1/2	1/4	1/2	2	3/8
4	4.50	10 5/8	1 1/2	1/4	1/2	2	3/8
5	5.63	12	2	1/4	1/2	2	1/2
6	6.625	14	2	3/8	3/4	2	1/2
8	8.625	17 3/4	2 1/2	3/8	3/4	2 1/2	1/2
10	11.750	22 1/2	2 1/2	3/8	1	2 1/2	1/2

The clamp shown here consists essentially of two parts, the collar which clamps to the pipe wall, and the supporting rod which carries the load when the pipe is being hoisted. Both parts are easy to make and assemble. Here is how to do it:

The collar is formed from a section of steel bar. Dimensions for this bar are given in Fig. 2. After cutting the bar to proper length, *L*, place it over a section of pipe on which the clamp will be used. By alternately heating with the blowpipe and pounding with a hammer, shape the bar to the contour of the pipe. After the bar has been properly shaped, bend the ears by placing the ends of the bar in a vise. In Fig. 2, *E* shows the amount the ear should extend after bending. Dimensions for the bolt holes are shown in column *F*. These holes may be pierced with the cutting blowpipe or drilled. Place the holes as close as possible to the bends in the collar, allowing enough space for the head of the bolt and the nut. This assures maximum gripping pressure over the greatest area of pipe without bending the ears.

The diameter of the supporting rod is determined by the size of the pipe being handled. Bend the rod to the shape shown in Fig. 1 and weld the ends to the collar.

This is just one type of pipe clamp that can be made. By using your imagination, you can vary and improve this design and make a clamp suitable for your work.

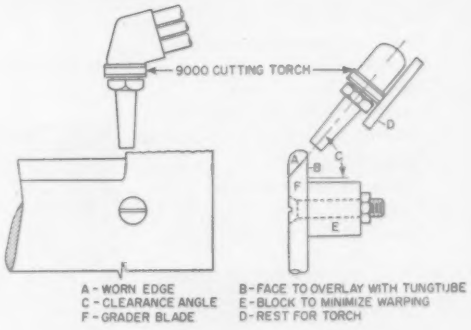
Road Grader Blades Quickly Resharpened with Oxyacetylene Flame Cutting Torch

USE of the oxyacetylene cutting torch for sharpening road scraper blades has proved economical and satisfactory. Over the years, this method has fast gained in popularity and is now standard practice for many welders.

Although some welders simply bevel the blade with the torch by hand, using no mechanical aids, others prefer to construct a suitable jig for the work. Such a jig may consist of a $2^1/_2$- x $2^1/_2$-in. 10-ft. bar of steel drilled for bolting the scraper blade down to minimize warping. Another steel bar or angle is placed in such a position as to enable the operator to steady the cutting torch to insure a straight cut at the desired angle. An Airco Style 144, No. 1 tip, used with an Airco Style 9000 cutting torch, will do this job most satisfactorily.

Various angles are cut but a 60-degree angle is most frequently used as it gives good clearance behind the blade. When the cutting torch is used, the blades warp in only one plane, and can be easily straightened or in some cases can be rectified by simply bolting on the scraper. But when a blade is drawn out by heating in a forge and hammering on an anvil, it is likely to warp badly in two directions and require considerable work to put it back into usable shape.

In a specific instance six 6-ft. blades were sharpened by torch cutting in $1^1/_2$ man-hours, using 95 cu. ft. of oxygen and 20 cu. ft. of acetylene.



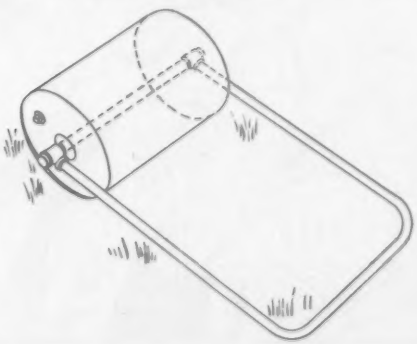
When a blade is sharpened by torch cutting and when overlaid with Tungtube 20–30, it lasts longer than when forged out. The illustration shows side and end views of a scraper blade being sharpened by torch cutting. The torch is guided by a steel bar, *D*, while the blade is bolted to the bar *E*.

This application fits into the equipment of any welding or job shop and, by both speeding the work and improving its quality, it should result in greater profits and well-satisfied customers.

Lawn Roller

CUT an old water boiler* to size, first making sure that it is properly vented. Or perhaps you can find an open-end steel drum* with a cover, just the right length.

Braze-weld a pipe in position through the center of the drum. Be sure that the joints are watertight. Insert a slightly smaller pipe for the axle and braze-weld pipe tees at each end. Then braze-weld the handle to each tee. The drum and larger pipe will roll around the axle—the smaller pipe. A hole at one end (large enough to insert a garden hose nozzle) tapped for a pipe plug, completes the job. Fill the roller with water to make it as heavy as you want.



* Before you cut the tank or drum, make sure that you clean it thoroughly. It may have contained flammable liquids. Follow recommended procedures for cleaning containers that have held flammable materials.

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LIL CHAMP
CASHIER
FROM ALL OF US TO ALL OF YOU
MERRY CHRISTMAS
AND A
HAPPY NEW YEAR
MAN! WHAT'S GOING ON HERE? I HAVEN'T SEEN THIS MUCH MONEY SINCE THE BANK BOILER BLEW UP!!!
SHIP YARD
VICTORY
IT'S BEEN THE SAME EVERY YEAR SINCE WE STARTED USING CHAMPION ELECTRODES! WITH MANAGEMENT SHOWING GREATER PROFITS - WE GET OUR SHARE IN HIGHER WAGES!!!
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CLEVELAND, OHIO East Chicago, Ind.

the AMERICAN WELDING SOCIETY

activities • related events

March 1951 Journals

Due to heavy demands the supply of the March 1951 WELDING JOURNAL is exhausted. The Society respectfully requests that any member who no longer has need for his copy of the March issue return same to F. J. Mooney, Asst. Sec., AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Return postage will be sent on request.

Honored by American Welding Society

Casin W. Obert, engineering consultant for Linde Air Products Co., a Division of Union Carbide and Carbon Corp., received the Samuel Wylie Miller Memorial Medal at the 1951 Annual Meeting of the AMERICAN WELDING SOCIETY at the Hotel Book-Cadillac, Detroit, on Thursday, October 18th. This medal is awarded annually by the SOCIETY for conspicuous contributions to the advancement of welding or cutting metals.

The award was made to Mr. Obert for "four decades of creative contributions to the art and science of welding."

Mr. Obert was born at Unadilla, Mich., in 1876. He attended the University of Michigan for two years, then graduated in 1902 with a degree in Mechanical Engineering from Columbia University.

For several months before graduating from Columbia, and until 1909, Mr. Obert held a series of editorial positions on technical magazines. From 1909 to 1912 he conducted his own engineering business, and while so engaged, he staged an elaborate running test of the producer-gas internal combustion engine power plant. This test, later presented in a paper to the American Society of Mechanical Engineers, plus his editorial work, were two of the factors that led Mr. Obert into a 40-year, active association with technical societies.

His affiliation with technical and engineering societies began in 1904 when he was elected to associate membership in the American Society of Mechanical Engineers. In 1912 he became secretary of the A.S.M.E. Boiler Code Committee and assistant secretary of the A.S.M.E., following which he was advanced to full membership in the A.S.M.E. in 1914. In 1916 he became secretary of the American Society of the Heating and Ventilating Engineers, while continuing to hold the post of Secretary of the A.S.M.E. Boiler Code Committee. In 1924, he resigned as Secretary of the American Society of Heating and Ventilating Engineers to become design engineer for a boiler manufacturer, while still holding the committee secretary post. In 1927, he left the boiler manufacturer to become a consulting engineer for Linde, and at the same time was elected to membership in the AMERICAN WELDING SOCIETY in 1927.

C. W. Obert

With Linde Mr. Obert has done considerable research on the welding of boilers and other pressure vessels. Part of the research, which included a series of over 1000 tensile and bend tests on welded specimens, led to the establishment of welding rules for boiler construction by the A.S.M.E.'s Boiler Code Committee in 1931.

While with Linde Mr. Obert continued his technical society activities, and for some time was active on a number of committees. Although he has since curtailed much of this work, he is still an honorary member of the A.S.M.E. Boiler Code Committee, a member of the New York State Boiler Advisory Board, and registered professional engineer in that State. He is also honorary member and member of the Executive Committee of the National Board of Boiler and Pressure Vessel Inspectors. In addition he has been a member of the Editorial Committee for all three of the A.W.S. Welding Handbooks.

Mr. Obert is a resident of Norwalk, Conn.

W. H. Bruckner Lincoln Gold Medalist

Dr. W. H. Bruckner was awarded the Lincoln Gold Medal for his paper entitled, "The Micro-Mechanism of Fracture in the Tension Impact Test," as published in the September, 1950 Supplement to THE WELDING JOURNAL.

W. H. Bruckner

Dr. Bruckner's biography was published in the November 1951 issue of THE WELDING JOURNAL, but, unfortunately, the wrong photograph was used. A correct photograph is reproduced herewith.

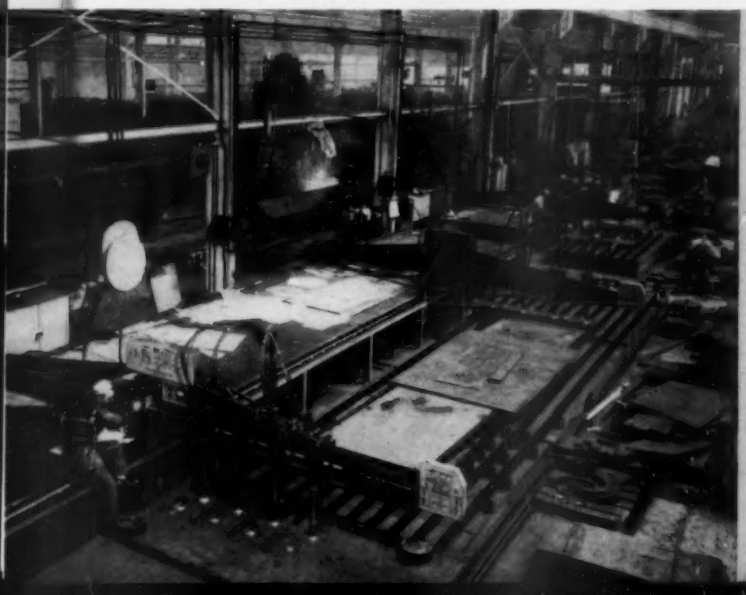
Exemption from Dues

The AMERICAN WELDING SOCIETY was formed in 1919. Many of the Charter Members of the National Society have maintained uninterrupted membership since its formation. However, the requirements for application during the first decade of the SOCIETY's existence did not enforce the registration in application of the applicant's age. Accordingly the SOCIETY's records do not disclose the age of many of its oldest members.

In the SOCIETY's Current By-Laws there are the following provisions, in Article IV, Dues and Fees, Section 4, Cancelled Dues:

"Any Member or Associate Member who shall have paid his dues for thirty-five (35) years, or who have paid his dues for thirty (30) years and having reached the age of sixty-five (65) years, shall there-

After 69 years of service, famous old Brooklyn Bridge is being remodeled. The bridge is being strengthened with new metal and roadways are being widened to provide additional traffic lanes. In this picture NCG's Torchweld "75" Cutting Torch and NCG gases are being employed in the demolition of the north roadway. "Time is an essential factor in this job and NCG equipment and gases have played an important part in speeding up the work," states Arthur J. Klevens, Vice President, J. K. Welding Co., contractors handling this mammoth rebuilding job for New York City's Dept. of Public Works.



Three NCG automatic flame cutting machines help speed production at the Whiting Corporation, Harvey, Ill., one of the nation's leading producers of foundry and railway equipment, material handling equipment, rotary shears, chemical equipment and special machinery. Two of the machines are mounted on one long table to provide a 40-foot cutting length. Parts being cut in this picture are for Whiting's new "Trackmobile." Whiting has used NCG cutting equipment for ten years.

AT RIGHT: Rego KX Hand Cutting Torches and NCG's Cut-O-Matic and RS Cutting Machines speed production at Welded Steel Shapes, Inc., structural steel fabricators at Coatesville, Pa. NCG's pipe-line system, fed from portable banks, keeps NCG gases flowing conveniently and economically at this modern shop where work ranges from the fabrication of buildings and bridges to farm equipment.

Get it done faster and better with NCG

In plants and shops across the country NCG equipment is proving that it can get work done more profitably

In times like these when all basic costs are high, one of the solutions for profitable production is selecting tools that will help get jobs done easier, faster and better—that can be depended on, too, to stand up under heavy use without costly maintenance.

NCG customers from coast to coast are getting this profitable kind of help from NCG equipment. You can get it, too!

Whatever your needs are for welding or flame cutting equipment, find out what NCG has to offer before you make a choice. Your nearest NCG office or the authorized NCG dealer in your locality is able and anxious to help you. And you'll like the interest they take in making your problems their own.

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after be exempt from the payment of further dues, except that the number of years for which dues were paid as an Associate Member shall be reckoned as nine-tenths (9/10) of their number in the above provisions. (Student Membership years not included.)"

Not until the end of 1954 will any Member be eligible for dues exemption under the initial provision. However, there may be Members who have reached the age of sixty-five and who have, without interruption paid dues for thirty years. Those Members would be eligible for exemption from further dues.

Accordingly we urge any Members who may qualify under those provisions to communicate with the Society's Secretary, providing him statement, with date of birth and applying for exemption from further dues.

Ship Structure Luncheon

Through the courtesy of the U. S. Coast Guard a number of interesting photos were taken during the luncheon given by Rear Admiral K. K. Cowart to members of the Ship Structure Committee and Authors of papers at the Ship Structure Sessions. The photo at the left shows Captain E. A. Wright, USN and Chairman of the Ship Structure Sub-Committee; Charles Jennings, President-Elect, American Welding Society; Rear Admiral K. K. Cowart, U. S. Coast Guard, Chairman Ship Structure Committee; H. W. Pierce, President, American Welding Society, and Rear Admiral R. L. Raney, USCG Commander.

Below is a photo taken during the luncheon at the Book-Cadillac Hotel, Detroit.

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Saxe Welding Connection Units position and secure structural parts to be welded.

Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

Write for 1951 edition, Structural Welding Practice Manual.

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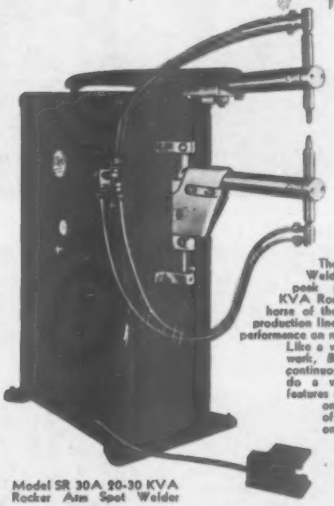
ROCKER ARM SPOT WELDERS



Model SR 30A 20-30 KVA Rocker Arm Spot Welder

These two Banner Rocker Arm Spot Welders will help gear your plant for peak production! The speedy 20–30 KVA Rocker Arm Welder is truly the race horse of the team as it does a fast, accurate production line job and provides a wide range of performance on mild steels.

Like a work horse in its steady operation on heavy duty work, Banner's 50–75 KVA Spot Welder delivers continuous high production . . . has a capacity to do a variety of welding jobs. Special design features of both machines provide a 1 to 1 ratio on the 24" throat to permit welding of certain applications usually done only on a Press Type Welder.

Model SR75A 50-75 KVA Rocker Arm Spot Welder

Banner Welders Offer Outstanding Construction Features

FRAME: Sturdily constructed of heavy ⅜" boiler plate formed and securely welded. For easy servicing the 50-75 KVA machine has detachable side panels and the 20-30 KVA unit has a large rear door.

CONSTRUCTION: Heavy castings of special, hard, high strength, high conductivity copper alloy are employed throughout the 50-75 KVA model. Enclosed heavily ribbed rocker arm is of grey iron casting mounted in a pivot pin assembly with Oilite bushings.

50-75 KVA welder has a 28" dimension from the pivot point to the end of the push rod connection facilitating better than 1 to 1 pressure ratio on 24" throat. This unusual feature permits the welding of certain applications normally practical only on a Press Type Welder.

TRANSFORMERS: Both welders operate with 220 volt or 440 volt water-cooled transformers built in accordance with industry specifications and are equipped with 8 point Heat Selector switches, the larger units having the series/parallel type permitting heavier duty.

Carefully engineered construction of 50-75 KVA Banner Welder makes it the leader in the field. Advantages are: *fast action*—capable of approximately 180 spots per minute—and *accurate performance* due to balanced moving parts and Oilite bushings throughout. Quality accessories include double-acting air cylinder, four-way solenoid valve, regulator, strainer and gauge.

BANNER is in a NEW Home!

To meet the growing demand for its welders, Banner announces the opening of larger and greatly expanded facilities for the manufacture of their resistance welding equipment.

Specific data sheets and catalog available. *Write today!*

Banner manufacturers a complete line of Gun, Seam, Rocker Arm and larger Press Welders and Specials to 200 KVA. Inquiries invited.

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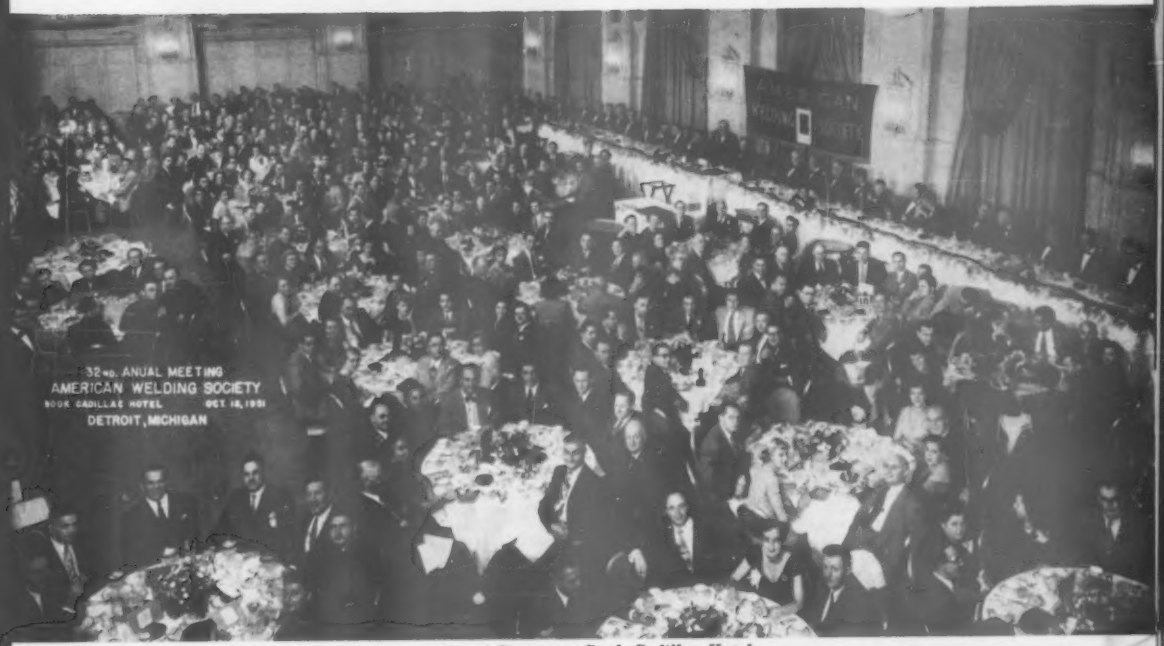
Annual Meeting Pictures
American Welding Society, Book-Cadillac Hotel, Detroit, Michigan—Week of Oct. 15, 1951

Receiving Line at President's Reception

Front Row, Left to Right—Mrs. Keith Sheren, Mrs. Edgar B. Brown, Mrs. Homer Morrison, Mrs. Fred L. Plummer, Mrs. Charles H. Jennings, Mrs. Harry W. Pierce, Mrs. R. H. Bennewitz.
Back Row, Left to Right—Keith Sheren, Chairman Detroit Section; Edgar B. Brown, Convention Committee Vice-Chairman; Homer Morrison, Chairman Convention Committee; Fred L. Plummer, 1st Vice-President; Charles H. Jennings, President Elect; Harry W. Pierce, President; Eric Seabloom, 2nd Vice-President.

Detroit Section Officers

Front Row, Left to Right—Don H. Corey, Past-Chairman, Edgar B. Brown, Past-Chairman, George N. Sieger, Past-Chairman and Past-President, Thomas J. Crawford, Past-Chairman and District #4 Vice-President, J. Ray Stitt, Past-Chairman, Secy.-Treas. and Member Board of Directors.
Back Row, Left to Right—Present Officers—Keith Sheren, Chairman, Roy L. Clark, Assistant Secretary, R. H. Bennewitz, 2nd Vice-Chairman, J. M. Johnston, Assistant Secretary, A. E. Lindsey, 1st Vice-Chairman, L. A. Strobel, Member Executive Committee.



Annual Banquet—Book-Cadillac Hotel

President's Reception

American & Foreign Welding Conferences International Institue of Welding

Scenes at the Registration Desk

President's Address—*by H. W. Pierce*

It is customary each year, at this Annual Meeting of our SOCIETY, for your President to report on his stewardship, to acquaint you with the state of the SOCIETY's affairs, and possibly to furnish some recommendations for future activity. If that custom appears to provide an opportunity for oratory, I can assure you that nothing is further from my mind.

Those who are held responsible for the success of any cooperative enterprise must measure the degree of success attained during the year in three ways: First, in the accomplishment of stated objectives; second, in the growth of the organization; third, in its business or financial aspect.

The year has been outstanding in technical and section activity, the former back in full swing following the completion and publication of the recent and successful edition of the *Welding Handbook*. Older codes, specifications and guides are being overhauled and brought up to date, while the demands of new processes and techniques are being translated into similar publications. The action of your Board of Directors in making a portion of the Reserve Funds available to spark this resurgence and enlarge the technical staff has already borne fruit.

Section meetings generally show greater attendance and more enthusiasm. While I regret that time available did not permit visiting as many of these meetings as I should, it was possible to visit some fifteen Sections from Boston to the West Coast. Several district or joint Section meetings were also attended. These I consider particularly noteworthy, and a healthy tendency to provide large and important welding events well off the beaten track of our Annual Meetings.

The present Annual Meeting has been one of our best, and reflects great credit on those who have given so freely of their time to make it so successful. The host Section, Detroit, has our sincere admiration and congratulations, and likewise, those who served on National Committees, and our Headquarters Staff.

The activity trend is important to my mind because I believe it marks a change in eras. Welding has gone through the stage predominantly pioneering in nature, wartime expansion with considerable recession in returning to former peacetime products and, now, a much sounder stage of solid growth based on research, engineering development and competitive application.

It is tempting to point out that the year 1950–51 has seen the reversal of trends existent since the close of the hectic war years both in membership and financial operation. In the membership figures we show for the first time in six years a positive gain in membership. In my thinking, the fact that this is a reversal is far more important than the numerical gain. Like the rolling snowball, movement positive or negative tends to become cumulative. We have started to roll in the right direction.

Although the same adverse conditions—steadily rising costs in the face of nearly static income—still exist, the SOCIETY, at the close of the current fiscal year, will be "in the black" for the first time in four years. Income will exceed expense by a small but positive amount—again, the reversal of a trend.

It is tempting, as I have said, to spotlight these facts and somehow create the impression in your minds that I, as your President, have been responsible for these unquestionable achievements. To do so would be downright dishonesty.

These accomplishments, and the foundation for greater ones, have been the work of many heads and hands. Membershipwise, increased Section activity and an increasing realization on the part of members everywhere that the benefits of this SOCIETY are real and tangible has been translated into greater solicitation among the thousands of prospective members. Yet the potential has hardly been tapped.

On the financial side, all credit goes to close cooperation of the loyal and efficient Headquarters Staff and the Finance Committee. A realistic budget, extreme care in management at Headquarters, the elimination not only of any waste but of less essential operations were responsible for keeping expense within income, yet with measurable improvement in essential services.

The details of the past year's operations will be briefed later by our able Secretary, Treasurer and Committee Chairmen. Their full reports, when published, deserve your careful reading.

I entered upon the duties of this office with a feeling of deep obligation to the SOCIETY, not only for the honor of office but far more for the benefits received, directly and indirectly, during my years of membership. What effort I could put forward in behalf of the SOCIETY could only in part repay that debt.

At the end of the year, I find that the debt has been in no way reduced, in fact, it is much greater. If my regime has failed to register the positive steps I had in mind on entering office, I can only hope that some of the groundwork has been laid, some of the differences resolved and the way somewhat cleared for my able successor to achieve his goals. I assure him of my support, aided by a year which has added tremendously to my SOCIETY experience.

To my good friends Magrath, Greenberg, Spraragen, Mooney and all members of our Headquarters Staff, my very real gratitude for loyal and efficient performance of duty; to the Officers and Members of the Board, my deep appreciation of your cooperation, counsel and support; to those who served on committees or were called into consultation, my thanks for so cheerfully carrying out those assignments. I know you will extend the same or more to your new President.

Under the SOCIETY's By-Laws, a Past-President still has certain obligations and duties; he remains and should be a very active member. So, to all you members who have so honored me with this office, my thanks, but no farewell.

President Elect's Acceptance of Office—*by C. H. Jennings*

Mr. Pierce, members and staff of the AMERICAN WELDING SOCIETY, ladies and guests. It is indeed an honor to be elected President of the AMERICAN WELDING SOCIETY. It is also a great responsibility. I sincerely hope that during the coming year I can follow the example set up by my predecessors in carrying out these responsibilities and aiding in the continued growth and advancement of our SOCIETY. Under the guidance of President Pierce, the outgoing Board of Directors and excellent work of all the committees and individual members, our SOCIETY has grown and prospered. I can assure you that the aim and objectives of the new Board of Directors and Officers will continue to be the same.

The AMERICAN WELDING SOCIETY was founded to advance the art and science of welding. The progress in welding is proof that the SOCIETY has lived up to these objectives. We are an important part of the modern industrial age. Industry depends upon us and needs us. They depend upon us for technical information, for codes and standards and for guidance in all phases of metals joining. We have fulfilled these obligations in the past through technical activities work; THE WELDING JOURNAL; sectional, regional and national meetings and by consulting and advisory service of all types.

As each year passes, the science of welding becomes more complex. There was a time when one was an expert if he knew how to weld mild steel by one welding process. Today a welding engineer has to know how to weld by many different processes.

The AMERICAN WELDING SOCIETY has grown with the welding industry. We have many new and different problems facing us. We are now in a strong position and I am confident that our Officers, Board of Directors and staff members will do everything possible to continue this progress and to help you, the members, make this a banner year in every respect.

Report of Secretary Available on Request

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It's a neat job...and it's stronger

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● Welded piping systems are streamlined. They save space, are easier to insulate and are permanently leakproof.

For a complicated connection like this, use of the TUBE-TURN Welding Cross also means extra strength. This welding cross is made from the same seamless tubing and by the same process as TUBE-TURN Welding Tees. Bursting pressures obtained in tests of representative tees and crosses have averaged more than 25% higher than required by standard codes. This gives you extra quality at no extra cost.

Welding your piping with TUBE-TURN Welding Fittings means a neater design and stronger construction. Get in touch with your nearby TUBE TURNS' Distributor. There's one in every principal city.

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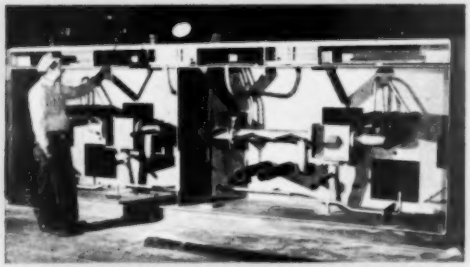
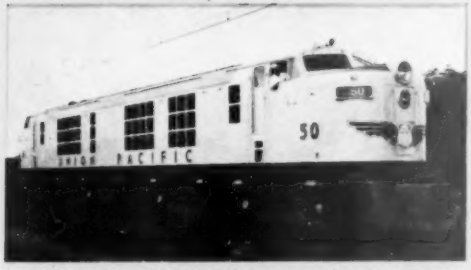
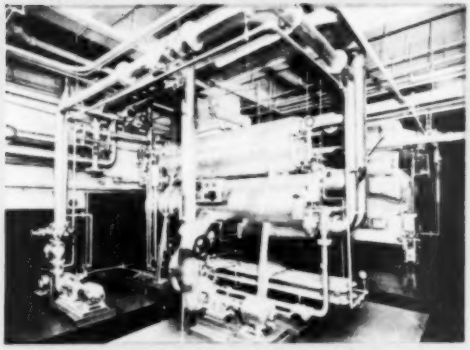
They build piping permanence into this equipment... with TUBE-TURN Welding Fittings



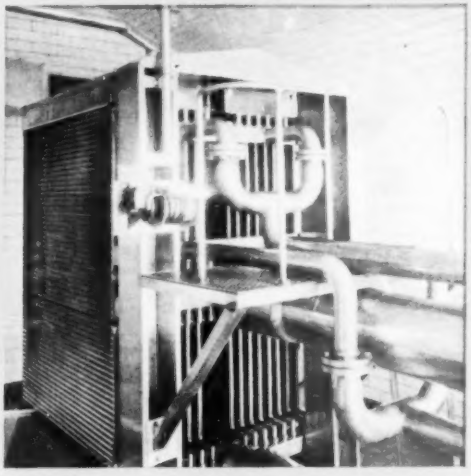
Hydroelectric projects like Grand Coulee and Hoover Dam represent a tremendous investment in equipment. So the Woodward Governor Company, builder of governors which control the big turbines, makes dependability a prime consideration. Critical piping on the governor sump base is joined with reliable TUBE-TURN Welding Fittings.



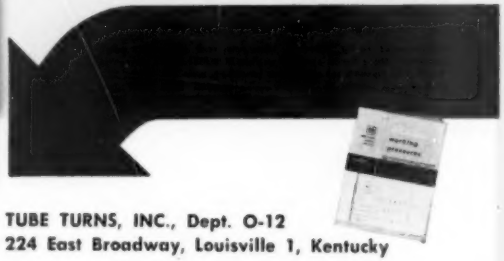
Here's the first gas turbine electric locomotive on the nation's railroads. With much of the equipment fitted into a limited space, failures in piping joints here would mean king-sized headaches. That's why piping joined with TUBE-TURN Welding Fittings is specified throughout. Despite hard usage characteristic of locomotive application, this piping stays strong.



Carrier Corp. engineers insist on rugged components for Carrier apparatus, such as this new refrigerating machine. Thus lines are welded with TUBE-TURN Welding Fittings to banish maintenance, conserve space too. The wide range of types, sizes, and alloys available in TUBE-TURN Welding Fittings and Flanges makes fabrication of a complex job like this easier.



A cool, clean bottle of beer starts with clean, leakproof equipment. That's why welded piping is used for this wort cooler, designed and used by the Falstaff Brewing Corporation. Pipe and TUBE-TURN Welding Fittings are made of stainless steel. Thus contamination, internal or external, is guarded against. Such installations assist Falstaff's premium quality control program, and help keep the plant spic and span.



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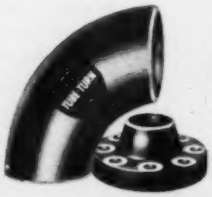

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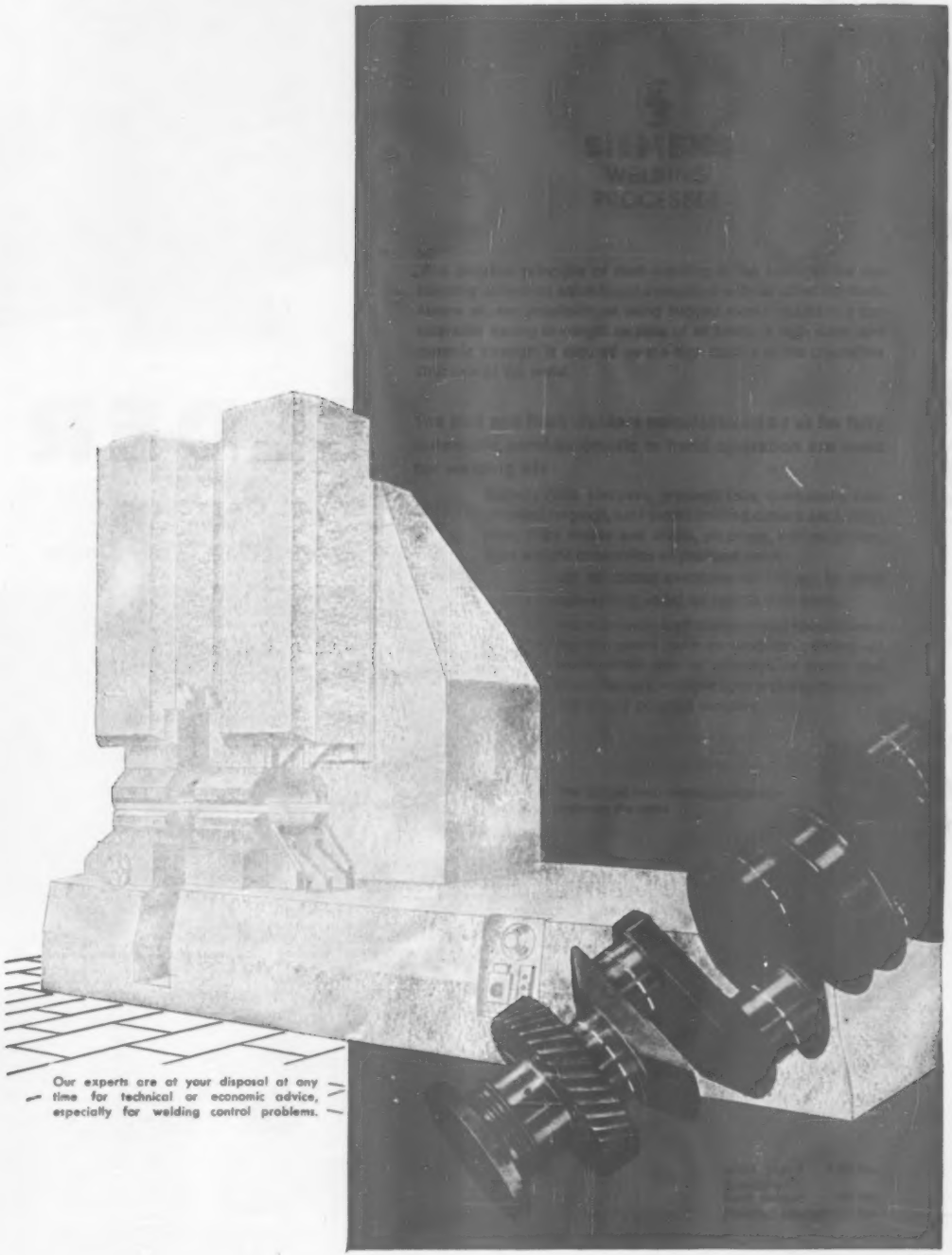


8/35

SIEMENS-SCHUCKERTWERKE AKTIENGESELLSCHAFT
Erlangen, Germany

New

New WD-4200 and smaller WD-4150 are compact, portable welders with wide current range and versatility of operation. 30 volts, 50% duty cycle—220/440 volts; 60 cycles; 150 and 200 amps.

D-C WELDER

Features Versatility and Ease of Operation, High Production, Low Costs

VERSATILE

The new G-E WD-4200 can be used with:

- a variety of electrodes from $\frac{1}{16}$ to $\frac{5}{16}$ inches, and as large as $\frac{1}{4}$ in. for special short jobs
- wide current range—from 30 to 250 amps, or as low as 15 amps with a special, easily-installed resistor
- both Inert-Arc and metal-arc welding

EASY TO OPERATE

Operators like the new manual starter, simple dial controls and a stable arc which can be maintained at any current setting. The compact, lightweight WD-4200 is easily portable, too.

INCREASES PRODUCTION

High instantaneous voltage makes the arc strike every time on heavy or light-gage stock, reducing spoilage.

The WD-4200 is suited to both fast metal-arc welding and Inert-Arc welding of copper, stainless steel and alloy steels, including sheet metal from $\frac{1}{32}$ to $\frac{1}{4}$ inches.

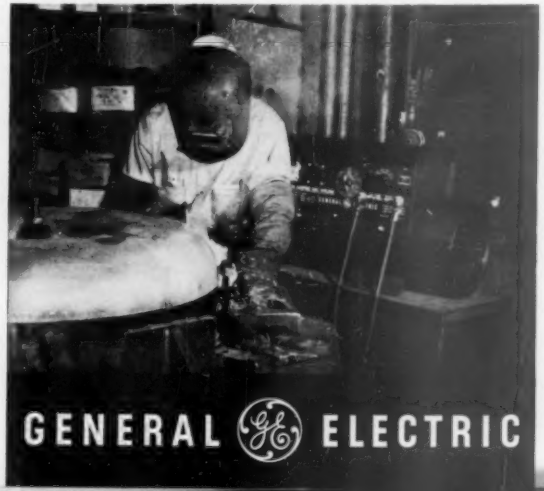
LOWERS COSTS

Reduces Power Costs 10 to 15%

The WD-4200 substantially lowers costs because the full range of current is obtained without the use of a current-limiting resistor.

Limited current peaks conserve electrodes and help prevent spatter and burn-through. You save on original cost, production *and* upkeep expense!

It's easy to select *just the right current* (above photo.) The operator can use a wide variety of electrodes for either Inert-Arc or metal-arc welding.



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Please send me your bulletin, GEC-847, which describes the newest G-E WD4200 Generator Welder.

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.....Planning immediate project

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Position.....
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PERSONNEL

Brown Made Assistant Sales Manager

Edgar B. Brown has been named Assistant Sales Manager of the Detroit Branch of the American Brass Co. His appointment became effective on Oct. 1, 1951.

Mr. Brown has been associated with the American Brass Co. for the last fifteen years. He started with this company in 1936 as Welding Engineer. In 1942, he was made Development Engineer, and in 1949 he became Sales Engineer. Prior to 1936, Mr. Brown was connected with the Lincoln Electric Co., U. S. L. Battery Corp. and Plymouth Division of Chrysler Corp.

In 1928, he graduated from the University of Michigan with the degree of Bachelor of Science in Electrical Engineering.

Mr. Brown is a member of the AMERICAN WELDING SOCIETY and has been extremely active in the affairs of the Detroit Section since 1943. He served as Chairman of the Reception Committee during the 1943–44 fiscal year and was on the Program Committee during 1944–45. Thereafter, he held the following offices: Assistant Secretary, 1945–46; Secretary-Treasurer, 1946–48; 2nd Vice-Chairman, 1948–49; 1st Vice-Chairman, 1949–50; and Chairman, 1950–51. In 1951, he was made Vice-Chairman of the National Convention Committee. Mr. Brown has addressed section meetings from Rochester to Oklahoma and co-authored an annual meeting paper in Chicago in 1950.

In addition, Mr. Brown holds a membership in the Engineering Society of Detroit and in the Society of Automotive Engineers.

Irrgang Elected Lincoln Executive Vice-President

William Irrgang has recently been elected Executive Vice-President of The Lincoln Electric Co.

He started with Lincoln in 1929 and for the past twenty-three years has been engaged in various phases of plant operation. As a methods engineer, he developed manufacturing methods and machinery for reducing the cost of welding electrodes. For the past six years as Director of Plant Engineering, he supervised the improvement in welding machine manufacturing methods which have been installed in Lincoln Electric's new plant, occupied in October. His department has had charge of the entire plant engineering project of Lincoln's new factory.

Irrgang was born in Germany and is a graduate electrical engineer from the State Technical School in Cologne. He came to the United States in 1928.

Cavanagh Joins Alloy Rods

J. O. Cavanagh, veteran of 15 years in the research and development of arc welding electrodes, has joined Alloy Rods Co., York, Pa., in the capacity of Technical Director.

The Alloy Rods Co. manufactures alloy arc-welding electrodes for stainless steel, armor welding, bronze and cast iron, hard facing, tool steel and other applications.

Mr. Cavanagh is a graduate chemical engineer from Illinois Institute of Technology, where he obtained his B.S. degree in 1932 and his M.S. degree in 1933. He is an active member of the AMERICAN WELDING SOCIETY.

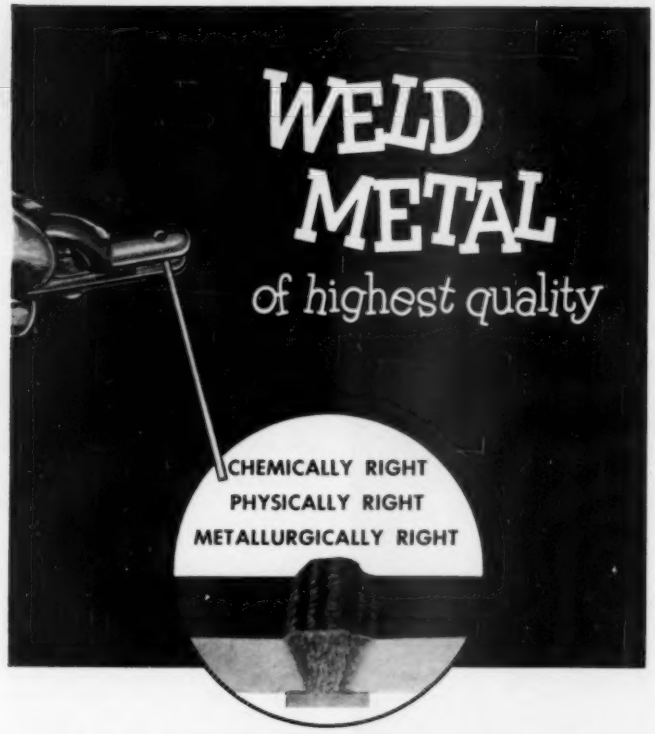
B. C. Tracey Retires from G.E.

After nearly thirty-four years of service, Bernard C. Tracey, manager of accessories and renewal parts sales of General Electric's Welding Dept., retired on Nov. 1, 1951.

Mr. Tracey joined G.E. on Mar. 16, 1918, at the Company's Schenectady (N. Y.) Works, where he worked to help standardize welding methods. In 1922, after a brief tour of duty as engineer of welding in the power and mining organization, he was transferred to the Company's Merchandising Dept., Bridgeport, Conn., as assistant to the manager of welding sales. He returned to Schenectady in 1930 in the same position.

In 1948, Mr. Tracey was appointed to his present post and was transferred to the G.E. Fitchburg (Mass.) Works in that capacity.

Mr. Tracey, as a representative of the General Electric Co., was one of the organizers and a charter member of the AMERICAN WELDING SOCIETY in New York, served on many A.W.S. committees



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and was chairman of the Northern New York Section.

He has served as committee chairman for Industry, National Foundation for Prevention of Infantile Paralysis, as a member of the U. S. Federal Board of Vocational Training, and the Emergency Fleet Corp. In 1937 he received the Democratic nomination for the office of New York state senator and was nominated for member of the assembly in 1938.

In retirement, Mr. Tracey plans to make himself available to industry as a part-time consultant.

OBITUARY

Worthy Channing Bucknam

Worthy Channing Bucknam, who was awarded the James Turner Morehead Medal, in 1935, died September 7th in Stuart, Fla., after a month's illness. He was 86 years old.

Mr. Bucknam was awarded the Morehead Medal for his pioneering work on the development of oxyacetylene welding and cutting apparatus. He developed several of the early machines for mechanized cutting including the Radiagraph, Oxygraph, Pyrograph and Camograph.

He left his own business in 1910 to join Davis-Bournonville, Jersey City, N. J.

When the Davis-Bournonville Co. was merged with Air Reduction Co. in 1922, Mr. Bucknam joined The Linde Air Products Co.

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Because these welders give production such a lift, P&H has stepped up its delivery schedules to meet defense demands without delay. Get your production rolling in high gear. Order your P&H AC Welders today. Capacities up to 650 amps. Take advantage of this delivery situation while it lasts.

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NEWS OF THE INDUSTRY

Metal & Thermit Corp. Announces New Appointments

Metal & Thermit Corp., New York, announces the appointment of Robert T. Brown as district manager in Pittsburgh, Pa., where he fills a vacancy left by the resignation of O. T. Barnett. Mr. Brown came to Metal & Thermit from American Can Co. in 1943 and for the past two years has been district manager at Newark, N. J.

Nicholas Kiernan, who has been with the company for thirteen years and a member of its welding division's sales force in the metropolitan New York area since 1947, has been appointed district manager at Newark.

Plant Maintenance Conference and Show to Be Held in Philadelphia, Jan. 14-17, 1952

The Plant Maintenance Conference and Show will be held in Convention Hall, Philadelphia, Pa., on Jan. 14-17, 1952, under the auspices of the American Society of Technical Engineers and the Society for the Advancement of Management. Manly Fleischman, Administrator, Defense Production Administration, will be the principal speaker.

Particular problems to be discussed include maintenance of plant buildings, electrical equipment, mechanical equipment, power-plant and service equipment and materials handling equipment. General sessions will be on maintenance costs, project preparation, inspection methods, scheduling of maintenance work, training workers and supervisors, personnel, operating policies, safety and plant protection, housekeeping and welding.

A paper entitled "Welding in Maintenance" will be presented by Alfred A. Wald at the afternoon session on Wednesday, January 16th. Mr. Wald is Superintendent of Maintenance, Caterpillar Tractor Co., Peoria, Ill.

British Industries Fair Date Set for 1952

The 1952 British Industries Fair will be held in London and Birmingham, England, May 5th to May 16th, according to announcement in London.

More than 99,000 home buyers (United Kingdom) registered for the 1951 Fair, and 80,000 members of the general public were admitted at special hours. Nearly fifty thousand of these members of the public were included in special conducted parties from British factories so that workmen might see on display the heavy industry products they manufacture.

The 1952 Fair will again occupy three exhibit halls, Earl's Court and Olympia in London, and Castle Bromwich in Birmingham. Every square foot of exhibit space in the three buildings was utilized last year by nearly three thousand British manufacturer exhibitors, with a large outdoor area in Birmingham being allocated to road construction and other heavy machinery.

Special train service between London and Birmingham will be provided as in the previous years.

Burdett Oxygen Enlarges California Branch

The Burdett Oxygen Co. of Cleveland, Ohio, has announced the completion of the expansion of its plant at Huntington Park, Calif. Several thousand square feet of floor space have been added which will provide twice the production capacity.

Besides the new machinery and equipment for producing industrial gases, special facilities have been added for demonstrating the latest welding procedures.

The Burdett plant in Huntington Park was originally established in 1947 to service Burdett customers on the West Coast.

15-Ton Ore Bridge Erected

A new ore bridge with a free digging stocking capacity of 1165 tons of ore per hour has been erected for Carrie Blast Furnaces 6 and 7 of United States Steel Co.'s Homestead District Works, near Pittsburgh.

The structure, with a 186-ft. span, has a bucket capacity of 15 tons and was designed to supplant two $7^1/_2$-ton ore bridges.

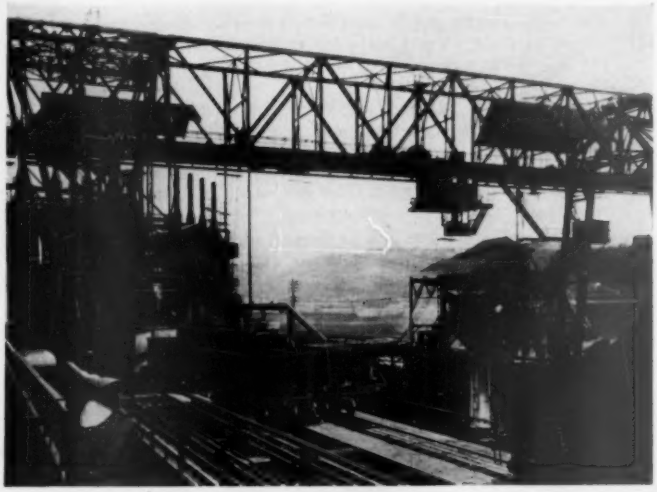
Dravo Corp., Pittsburgh, fabricated the entire structure, except the main span which was built by American Bridge Co. The latter Company also erected the new ore bridge which has an over-all weight in excess of 600 tons.

The bridge, running on rails, stockpiles ore from railroad cars and supplies ore to the conveying mechanism which charges blast furnaces.

The main span of the bridge is supported on two legs, one of which is 80 ft. high and the other 60 ft., from the runway to the bottom chord of the span. The shear leg, which is connected to the span by ball and socket joints to permit skewing of the bridge $^1/_{15}$ the distance of its length, is 70 ft. wide at its base. The pier leg is 60 ft. wide.

Each of the legs is supported on two 8-wheel truck units. A separate 45-hp. electric motor drives each truck unit, turning all eight wheels through worm and spur gearing. The wheels are 27 in. in diameter.

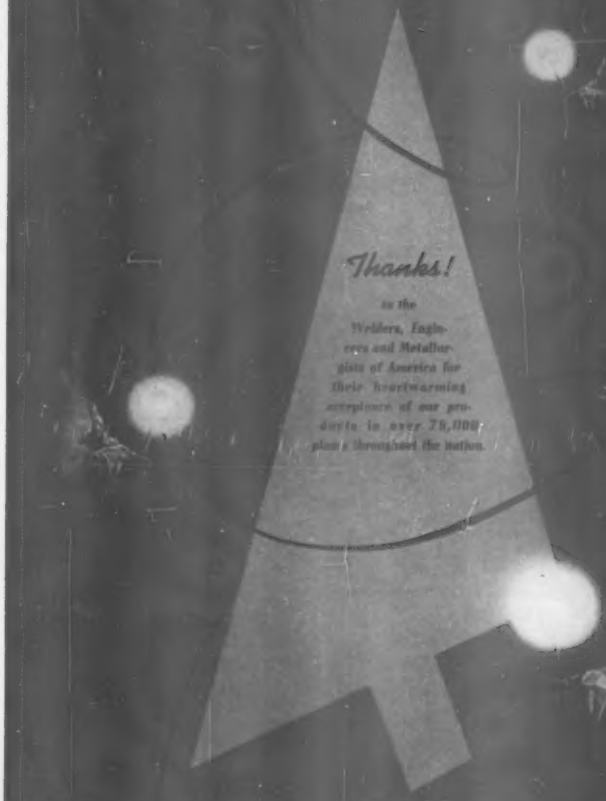
Dravo-designed rail clamps are installed on the trucks to hold the bridge stationary. These clamps operate automatically in case of power failure and if the wind velocity reaches 45 miles per hour as indicated by an anemometer mounted atop the main span. The bridge



15-Ton Ore Bridge Erected

WELDING

PEACE THRU STRENGTH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For the coming year . . as we have throughout the past decade . . . we shall continue our efforts to serve American industry and the Defense effort with:

★ the most advanced research program devoted to the development of new welding speeds and savings . . . already responsible for the development of more than 150 different welding rods, electrodes and special fluxes—

★ a fully-trained staff of over 200 District Engineers to help you solve your welding problems right in your own shop—

★ a continuous service of Technical Information bulletins, leaflets, and manuals on production welding as well as on vital maintenance work—

★ the Eutectic Welding Institute to teach advanced welding techniques to those who are concerned with maximum safety and efficiencies—

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—in short, a fully rounded program dedicated to serving YOU to the very best of our ability throughout the coming year.

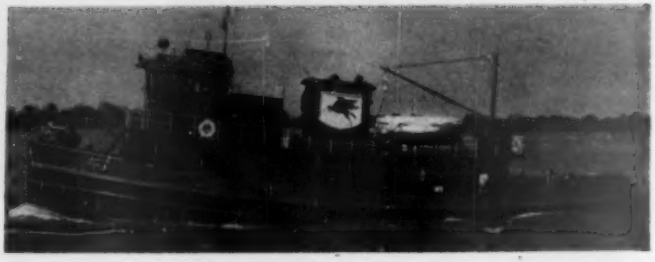
PRESIDENT

Season's Greeting

operator also has push button control over the rail clamping mechanism.

To operate the bridge and its equipment, a total of 11 electric motors are required. Combined horsepower of these motors is 888½ at varying time ratings.

Both the pier leg and shear leg are of all-welded construction while the main span is riveted. Structural members of the legs, and the trolley and bridge trucks were prefabricated at Dravo's Neville Island plant and shipped to the erection site.



Socony II

A.S.M Establishes Three $2000 Awards for Teaching Metallurgy

A total of $6000 annually has been set aside by the American Society for Metals as awards to teachers of metallurgy in any school in the United States or Canada. Three awards of $2000 each will go to those teachers of metallurgy whose performance and influence upon the general progress of the profession are judged best.

W. H. Eisenman, the Society's National Secretary, has announced that candidates for each $2000 award must be under 40 years of age on April 1st of the year during which the award will be made. Judging of the candidates' applications and particulars for the awards will be carried out by a special committee appointed by the board of trustees of the American Society for Metals.

All-Welded Tug Christened

The super tug *Socony II*, built by Avondale Marine Ways, Inc., for the Socony-Vacuum Oil Company, Inc., of New York, was christened at Avondale on October 10th.

The *Socony II*, an outstanding example of all-welded steel construction, is of the conventional type and was designed by Socony engineers. Of peculiar interest is the extra heavy hull plate of 5/16 thickness used below the water line and the doubler strip in the bow which were also provided for ice breaking. The rugged service to which this tug will be subjected requires, in addition, extra heavy and closely spaced framing for suitable reinforcing. The dimensions of the *Socony II* are as follows: Length OA 102 ft., 6 in.; beam, molded 25 ft.; depth, molded 12 ft., 9 in.; draft forward 9 ft., 9 in. and draft aft 11 ft. The *Socony II* has a gross tonnage of 207.

The main engine of the *Socony II* is General Motors Model 16-278A, 16-cylinder, 2-cycle, solid injection engine with a horsepower rating of 1640 hp. at 750 rpm.

Additional characteristics of interest are the fuel tank capacity of 27,300 gal. and a 2000-gal. fresh water tank which afford a cruising range of 7500 miles. Tug has a net tonnage of 100 tons and has a tow-line pull of 50,000 lb.

In general the *Socony II* is a husky, highly maneuverable tug with all the flexibility required for close harbor work and with adequate power and ruggedness for tough assignments.

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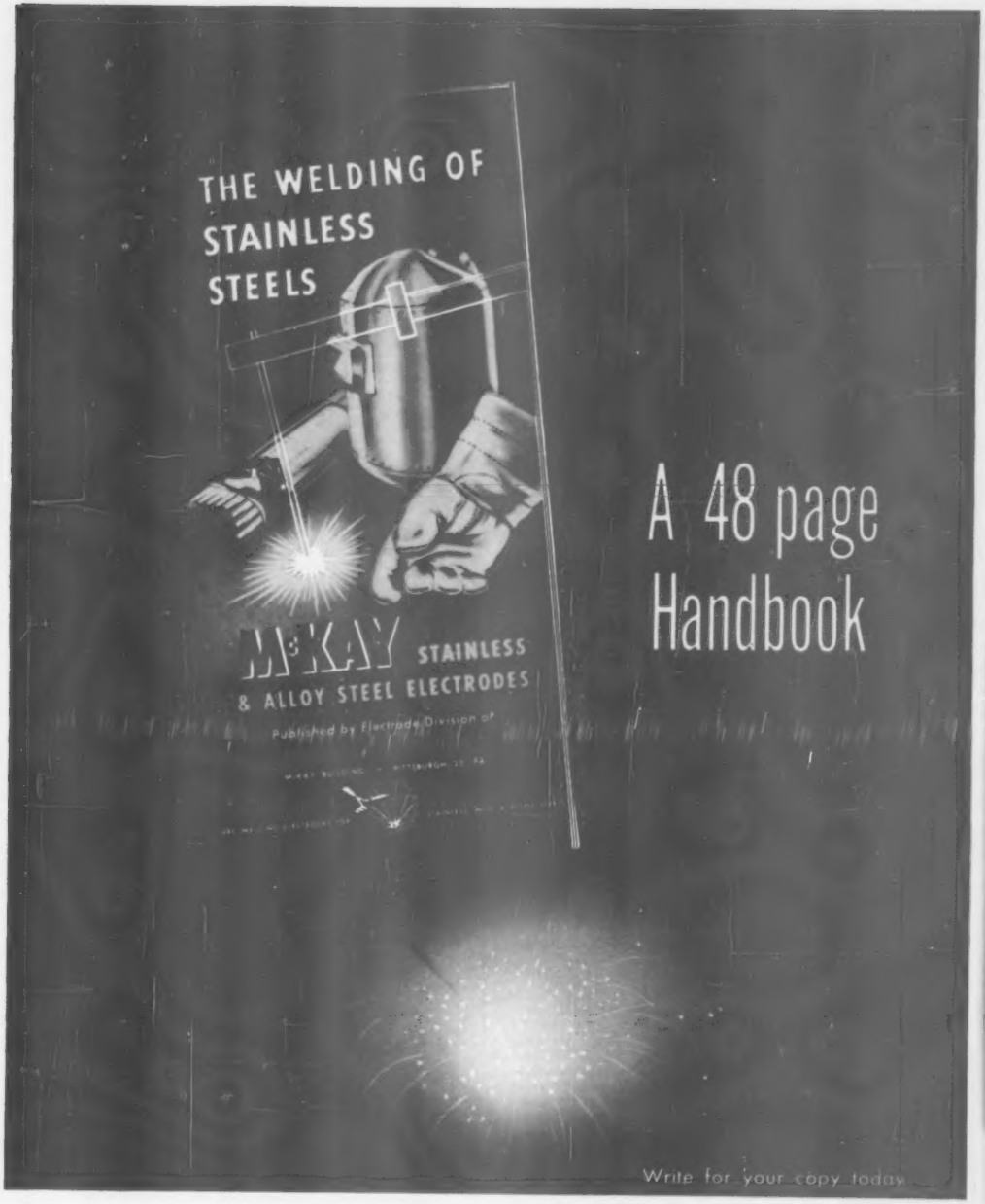

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Detroit Convention Hall

Dynamic Detroit is preparing plans for a combined Convention Hall and Exhibits Building over 1200 ft. long, with the world's largest welded rigid frames in the world's longest welded rigid frame building. It will be part of the new Civic Center along the river front within walking distance of City Hall. Estimated cost of $14,000,000 is being raised in part by public contributions through Detroit's 250th Birthday Festival Committee, the remainder to be paid for by the City, Giffels & Vallet, Inc., and L. Rosetti. Associated Engineers and Architects, are preparing the plans with Martin P. Korn, Consulting Engineer on design of the welded rigid frames.

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ARC-DRIVE CONTROL
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...Instantaneous response to arc-load changes
...Instantaneous recovery
...Reduced arc blow
...Completely adjustable by operator

Westinghouse RA Welders with new positive arc-drive control now prevent shorting when used on "drag" welding applications. In addition, they allow complete penetration on root passes of vertical and overhead welds. Arc-drive control is obtained by adjusting the ratio of short-circuit current to welding current without changing open-circuit voltage. Actual amount of arc-drive current can be varied by the operator.

For information on this improved RA Welder or other Westinghouse Welding Equipment, write Westinghouse Electric Corporation, Dept. DC 85, Welding Division, Buffalo, New York. J-21607-C

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Silver brazing, with relief annealing, assures gas tight and wholly dependable joints and — since both fuel gas and oxygen are separately conveyed — in independent tubings — no gas flows within the torch handle — this for your safety.

No gas flows in the torch handle — it's safe.

For safety sake each gas, the oxygen and the fuel gas, is separately conveyed from the torch needle valve body to the torch head — no gas flows in the torch handle.

For safety sake both the oxygen and the fuel gas tube is securely and permanently fastened by the most modern, fully automatic, silver brazing process which controls both temperature and timing.

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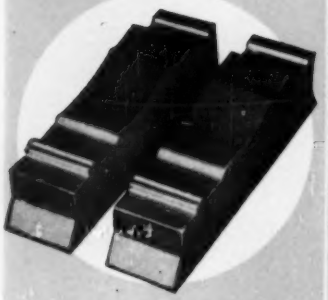

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Just think — when you order "cast-to-shape," "cast-to-size" AMPCO WELD dies, they come to you with tolerances of minus 0, +1/32" or plus 0, −1/32". There's no machining, no time loss. All you have to do is just put in the cap-screw holes — and brother, you're in production.

You also get longer runs and lower costs, because these dies are made of alloys with high physical properties that meet or exceed RWMA specifications. If you're interested in longer runs for your money, place your order now for AMPCO WELD "cast-to-size" dies.

. . . and Ampco Engineering Service when you need it

Behind the famous AMPCO WELD line of resistance-welding products is a corps of experienced engineers, ready to help you solve your problems. Prompt service from these men is yours whenever you need it. Just get in touch with us.

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Japanese Stamp Honors Welding

The Japanese people do not have a cracked Liberty Bell they can weld up and ring out to proclaim their industrial recovery under American sponsorship, but according to The Lincoln Electric Co., they are putting the modern process of arc welding to other good use. A recent stamp issue honors this modern industrial process, picturing the welding of a locomotive. The 500-yen stamp shown is worth about $1.35.

H. C. Price Marks 30th Anniversary

The H. C. Price Co., one of the organizations that have pioneered in arc-welded pipe line construction, observed its thirtieth anniversary on Nov. 1, 1951. This firm was organized in 1921 when Harold C. Price opened the Electra Welding Co. shop in Bartlesville, Okla., with two helpers and one arc-welding machine. One year later, Mr. Price changed the company's name to Welding Engineering Co. and started contracting arc welding of large tanks on location. The firm grew rapidly in its operations and size and, in 1928, it entered the field of pipeline construction.

By 1940, it was operating more than 200 arc-welding machines in addition to a vast array of other necessary construction equipment, including trucks and tractors. There were 500 on the pay roll.

During World War II, the company expanded into general pipe-line construction and in joint ventures with associated companies, completed a number of large pipe-line projects built during that period. In addition, the Price organization extended its activities to shipbuilding and airplane-modification work.

Major jobs the H. C. Price Co., as it is now known, has carried out since the end of World War II included building of the "Biggest Inch" for Southern California and Southern Counties Gas Companies, then the largest-diameter pipe ever laid; and the "Toughest Inch," an outstanding pipe-line-construction feat for Columbia Gas System, Inc., in 1949.

Sigma Welding of Portable Trusses

Aluminum trusses are now being fabricated for the United States Air Force by sigma welding. These are to be used with lightweight roof sheathing for prefabricated hangars at jet plane stations. Since proximity to an ever-changing fighting front is an important consideration, the development of portable hangars is significant.

A special jig built for holding the trusses, positions the end sections to be welded. The sections are then tack welded, following which the operator makes the required welds in the truss.

Since in sigma welding the arc is maintained in a shield of argon gas between the filler metal electrode and the workpiece, sigma welds are clean and smooth. No flux is used. Sharp reduction of cleaning and finishing expenses cuts overall production cost. The sigma welding equipment has been supplied by Linde Air Products Co.

Sigma welding of portable trusses

Production Life Increased 900% by Hard-Facing Here

. . . and still no sign of wear!

A 3/16-in. layer of HAYNES STELLITE hard-facing alloy protects this punch mandrel from severe wear and galling. The hard-faced mandrel, used in the manufacture of pipe couplings, has already produced 10,000 pieces and still shows no sign of losing gage. Tool steel parts in this same service wore out after punching only 1,000 pieces; and punches of case-hardened steel had to be replaced after producing 500 couplings.

The couplings are made from pipe of 1/8-in. wall thickness and 5 5/16 in. diameter. Under a pressure of 20 tons, the pipes are expanded to 6 7/8 in. in diameter at the rate of one every two minutes. In this severe forming operation, the hard-faced ring on the mandrel stays out-to-gage 10 times as long as a tool steel ring and 20 times as long as a case-hardened steel ring. In addition, it does not gall and mark the inside diameter of the pipes.

Hard-facing is often the answer to serious wear problems in all types of machinery and equipment. By reducing wear at key points, it helps to cut maintenance costs and keep machinery running at peak efficiency. Write for the folder "Hard-Facing Materials Data" for a quick summary of HAYNES hard-facing alloys. It gives chemical composition, properties, uses, and forms of each alloy.

HAYNES TRADE-MARK *alloys*

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"Haynes" and "Haynes Stellite" are trade-marks of Union Carbide and Carbon Corporation.

NEW LITERATURE

Arc-Welding Accessories

Catalog EW-164 covers the various arc-welding accessories made available by the Hobart Brothers Co. Copies of this catalog may be obtained by writing to Hobart Brothers Co., Box EW-164 Troy, Ohio.

Booklet on How to Use a Torch

A new instruction booklet on how to operate a gas-welding or cutting outfit has been published by the National Welding Equipment Co. This publication was designed primarily for students of vocational training schools and may be obtained by writing for a copy of National Instruction Booklet to National Welding Equipment Co., 218 Fremont St., San Francisco 5, Calif.

Bronze Welding Rods

A new edition of the booklet, *Anaconda Welding Rods and Procedures*, has been announced. Applications and procedures are suggested for production and repair welding, and for building up worn surfaces with bronze rods. Welding techniques discussed include the oxyacetylene torch, metal-arc, carbon-arc and inert-gas-shielded arc. U. S. Navy and Federal Specifications, as well as other tabular data on copper and copper alloy welding rods are also included. Copies of this 24-page booklet (Publication B-13) mailed on request. Address The American Brass Co., Waterbury 20, Conn.

Data File of Welding Problems

A new "1951 Data File of Defense and Maintenance-Conservation Welding Problems" has been offered, free of charge, by Eutectic Welding Alloys Corp., Flushing, N. Y.

This new, plastic bound Data File contains well over 100 pages of profusely illustrated technical data on maintenance and repair welding problems and procedures. A portion of this material consists of issues of the company's wartime maintenance and production tips magazine, *The Welder* containing valuable information on metal-joining procedures perfected during the past war. Included, also, are data sheets and information on a full line of over 160 different Eutectic Low-Temperature Welding Alloys and latest developments in this field.

Copies of this new Data File may be obtained by writing Dept. "P," Eutectic Welding Alloys Corp., Flushing, N. Y.

Aluminum Bronze Alloys for Corrosion-Resistant Service

A completely revised 20-page bulletin, *PI-3*, produced in two colors, giving complete information on Ampco alloys (aluminum bronze) as applied in corrosion-resistant service, has been released.

This book includes corrosion-erosion-resistance and cavitation-pitting data along with physical and chemical properties of various aluminum bronze alloys recommended for such service. The metal-working characteristics of Ampco Grade 8 sheet and plate are included as are the welding advantages of this alloy. Information concerning corrosion-resistant aluminum bronze centrifugal pumps, plug valves, pipe, tube, fittings, tube sheet and available testing facilities are included.

A free copy of this bulletin can be obtained by writing Ampco Metal, Inc., 1745 S. 38th. St., Milwaukee 46, Wis.

Manual on Casting-Welding Practice

As part of its continuing research and development program, Steel Founders' Society of America has just published a comprehensive new manual incorporating most advanced technical data on welding of steel castings.

Based on exhaustive studies carried out by the Society, member companies and professional research engineers, the 40-page report, *Recommended Practice for the Welding of Steel Castings*, comprises a valuable guide for steel foundries and related industries to use in establishing reliable welding procedures and experience-proved quality standards.

Recognizing that welding on occasion becomes an integral operation in the manufacture of steel castings, the manual likewise recognizes that industry also is actively engaged in cast-weld construction techniques (welding steel castings together to form an integral unit), and in fabrication of engineering structures through the welding of steel castings and wrought steel products (composite fabrication). Procedures outlined in the manual thus are equally adaptable to the needs and problems of the fabricator as well as the foundry.

While highlighting the fact that all steel is weldable, whether wrought or cast, the manual emphasizes that some steels are not as readily weldable as others, unless certain necessary precautions entailing special operational techniques are employed.

Bound in three sections, the Society manual includes detailed textual consideration of established procedures, tabular classification of electrodes, trade-name products and manufacturers for all classes of electrodes, compositions and recommended procedures for carbon steel and low-alloy steel castings, bibliography, etc. Numerous drawings are included to illustrate specific approved welding sequences.

Copies of the manual may be obtained by writing to F. Kermit Donaldson, Executive Vice-President, Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio. The price, fixed at cost, is 35 cents per copy.

Pipefitter Welder's Review of Oxyacetylene Welding

The National Certified Pipe Welding Bureau has recently published the pamphlet *Pipefitter Welder's Review of Oxyacetylene Welding* by Robert S. Green.

This is the second pamphlet written by Professor Green to assist Pipefitter Welders who are required to take qualification tests under the ASME Boiler Code. The first pamphlet was devoted to metallic arc welding. This pamphlet gives the pipefitter a like review of the oxyacetylene method.

The pamphlet is written in plain, direct language and is illustrated by clear line drawings. In the pamphlet the reader will find a step by step story of the test he is to take and the precautions he should employ to pass the test.

The purpose of this pamphlet is to give the pipefitter welder, who is required to take the test, confidence in his ability to make a good oxyacetylene weld which will enable him to pass the test.

Copies of the pamphlet can be obtained from the National Certified Pipe Welding Bureau, Suite 1401, 1250 Avenue of the Americas, New York 20, N. Y., for 50 cents per copy.

Silver Brazing Manual

The Research Division of the American Platinum Works has compiled and edited a complete library on low-temperature silver brazing into a 48-page pocket-size manual. This booklet, according to its publishers, takes its place as the most complete guide available on all aspects of silver brazing applications and procedures.

All generally useful information has been included in this work. More than 50 drawings and charts are used to illustrate the text. The booklet provides correct answers to general questions on low-temperature brazing, brazing alloys, joint design, preformed brazing shapes, plymetals, fluxing, heating methods, cleaning and inspection. Several of the reference charts are particularly useful to find at-a-glance specifications for silver brazing alloys, to check U. S. Government Specifications, Conversion Data, Brazing Alloy Quantities by Weight and a specially

5500 military planes this year...

means millions of welds—
over 90% of them are being produced with
Sciaky Spot and Seam Welders

WHAT'S so important about this fact? Simply this — the overwhelming preference for Sciaky machines in this most critical of all welding is proof of the superiority of Sciaky Three-Phase resistance welding.

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PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

PAGE WELDING ELECTRODES

designed graph to calculate the thermal expansion of metals and various silver brazing temperatures.

Copies of Silvaloy's *Complete Guide to Successful Silver Brazing* are available to engineering and brazing personnel of industrial manufacturers, libraries, schools, etc., upon request to the American Platinum Works, 231 New Jersey Railroad Ave., Newark, N. J.

Alloy Welding Electrodes

A new brochure entitled *Alloy Welding Electrodes for Defense Production* has just been published by Alloy Rods Co., York, Pa., manufacturers of alloy arc welding electrodes.

This brochure is designed to be of interest not only to industries with Defense Contracts involving welding operations, but also to the dozens of vertical applications in the broad sweep of American industry where modern welding procedures are employed.

Copies of this brochure may be obtained by writing for *Bulletin AR51-1* to E. R. Walsh III, General Sales Manager, Alloy Rods Co., York, Pa.

Hard-Facing Alloy Rods

Victor Equipment Co., Alloy Rod & Metal Div., 11320 S. Alemeda, Los Angeles, announces new bulletins available covering their complete line of hard-facing alloy rods. *Victor Tungsmooth*, a fine mesh tungsten carbide rod for electric or acetylene application; *Victortube*, a tungsten carbide rod for electric or acetylene application; and *Victoralloy*, a fabricated rod containing alloys in a tube and coated with a high-alloy coating, and designed for resistance to abrasion and ability to withstand severe impact.

This literature is available, upon request, from the company at the above address.

Farm Welding High-School Award Program

The Lincoln Arc Welding Foundation's $7000 Farm Welding Award Program for High Schools has been announced in an illustrated booklet showing over 50 farm shop projects. The Program offers awards to high school students who live on farms or ranches for the best descriptions of welded farm projects. Projects shown in the Rules booklet are ones for which awards were made in a similar program sponsored last year. Free copies of the Rules may be obtained from The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio.

Agricultural educators and leaders in 44 different states helped formulate the Rules for the Program, the purpose of which is stated as being to encourage students to study how welding can be used on farms to increase self-sufficiency, save time and labor. High-school students can compete for $5000 in awards

ranging from $600 to $25 by describing projects that have or could be made at home or school. Awards totaling $2000 will also be given to schools in honor of the main award winners. School awards are to be used for the improvement of shop mechanic courses.

Engineering Awards

The Rules and Conditions for the fifth annual competition of The Lincoln Arc Welding Foundation's Engineering Undergraduate Award and Scholarship Program are now available in a 24-page illustrated booklet. The booklet shows pictures of the design and research projects described in award papers of previous competitions. Brief descriptions of last year's award papers are also presented along with a bibliography of welding texts and references.

This annual program is a competition for undergraduate engineers to encourage them to use imagination and ingenuity in developing an engineering project in their own field. All registered undergraduate engineers are eligible to compete. Awards totaling $6750 are made for the best papers on design of machines or structures or separate components of machines or structures, in which arc welding is the method of fabrication. Welding research and maintenance projects can also be described. The sixty-three awards range from $1000 to $25. Scholarship funds totaling $1750 are also awarded to schools for the establishment of scholarships in honor of the main student awards.

Rules booklets may be obtained by writing to The James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio.

Ampco Welding News

The 3rd Quarter *Ampco Welding News* has just been released.

One informative case history contained in this issue discusses the technical aspects of fabricating Ampco Grade 8 idler drums for pickling service by using bare, coiled Ampco-Trode 10 with the inert-gas consumable electrode method where high speeds and excellent weld quality were required.

Also included in this issue is an article discussing the spot welding of Ampco Grade 8 sheet plus illustrated case histories of "Ampco-Facing" a heat exchanger head, drop ram and gear teeth.

Free copies may be obtained by writing Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Bulletin on Induction Heating

A new 12-page, two-color bulletin on equipment for induction heating has been announced as available from the General Electric Co., Schenectady 5, N. Y.

The illustrated booklet (GEA-5679) describes forging, hardening, brazing and annealing applications at 1000, 3000 and 10,000 cycles. It explains the components and requirements of induction heating with motor-generator type equipment and also covers such applications as forge welding, heating drill bits, continuous heating of moving strip and surface hardening.

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Or write ALUMINUM COMPANY OF AMERICA, 1944M Gulf Bldg., Pittsburgh 19, Pennsylvania.

Aluminum can be welded on automatic machines. Ask your distributor about a similar set-up for your product.

ALCOA FIRST IN ALUMINUM

NEW PRODUCTS

Carbide "Welding" Rods

The possibility of being able to "coat" metal parts with a relatively thin "skin" of ultra-hard, wear-resisting, tungsten carbide was forecast at the opening of the World Metallurgical Congress and Metals Exposition in Detroit, Monday, October 15th.

Carboloy Dept. of General Electric Co., Detroit 32, Mich., announced that it had completed basic laboratory development on a "weldable" tungsten carbide. It can be flowed onto metal surfaces, using conventional shielded electric arc welding equipment, available today in most of the larger and even many smaller metal-working plants (see photo).

Fig. 1 Producing a wear-resistant tungsten carbide surface on a draw roll with conventional shielded arc-welding equipment and a carbide welding rod

The new product is not as yet in production as a standard item but is characterized by K. R. Beardslee, General Manager of the Carboloy organization, as being in the "engineering appraisal" stage and undergoing field tests. It is made in experimental production at present in conventional welding rod form and sizes ranging from $^1/_{16}$ to $^1/_4$ in. diameter. When flowed on to a metallic surface such as steel or iron, it fuses and blends with the base metal and results in a surface coating containing approximately 70% of wear-resisting tungsten carbide.

Wear tests conducted so far indicate that such a surface has a wear-resisting ability of approximately 80% that of "undiluted" tungsten carbide—and about 15 to 20 times that of the best chilled cast irons of 43 to 67 Rockwell. Data on the latter comparison was obtained using an aluminum oxide dry abrasion test.

The process of skin coating ($^1/_{16}$ to $^1/_4$ in. thick skin) appears to be most suitable where it is desired to wearproof parts for

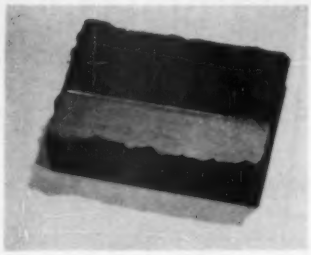


Fig. 2 The carbide surface produced by arc welding with carbide welding rods can be ground and polished if desired as shown here

which the use of solid carbide sections is inconvenient.

Although most suitable where high surface finish of the coating is not essential, a surface coated with tungsten carbide in this manner can be ground or polished using conventional equipment as for solid tungsten carbide parts.

Several types of "binders" have been used to date in the experimental hard-surfacing rods—including iron, nickel and cobalt. No final determination has been made as yet as to the class of application for which each type of binder is best suited.

High-Intensity Illuminator for X-Ray Film Viewing

An iris-diaphragmed, high-intensity viewer, that allows study of an extremely wide range of X-ray film densities in the industrial field, is announced by the General Electric Co., X-Ray Dept., 4855 Electric Ave., Milwaukee, Wis.

The wide range of viewable densities is made possible by two features—(1) the fact that the opening can be steplessly dilated or contracted, like a cat's eye, from a $^1/_4$-in. triangle to a 5-in. diameter circle, thus concentrating the light on the area in question, and (2) the fact that a special, new 100,000 candlepower lamp is used, with an average life of 1000 hr. at the rated voltage (115 v.). (This compares with 6 to 10 hr. life for the average photoflood lamp.) An even greater candlepower can be obtained by raising the voltage to 135, though this overload does shorten lamp life.

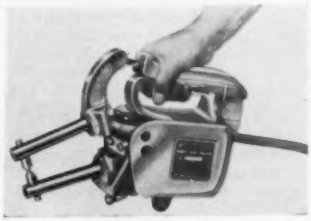
Film densities of from 0.5 to 4.5 can be penetrated by the new illuminator. This enables the radiographer to diagnose an object of greatly varying thicknesses with only one exposure. Also, it eliminates the need for retakes on overexposed films. To see through such films merely requires turning up the light intensity.

High-intensity illuminator for x-ray film viewing

The controls are recessed behind the surface of the illuminator, thus making it possible to move the radiograph to view any area desired without accidentally touching the controls. Use of a foot-switch leaves both hands free for manipulating the radiograph.

Portable Spot Welder

A new portable spot welder weighing only 24$^1/_2$ lb. including arms, electrodes and power cable, has been developed by Marquette Mfg. Co.



Portable spot welder

Featuring semiautomatic timing control and a new high leverage system developing extremely high, controlled pressure, the welder employs the "squeeze and heat" process. High amperage reduces metal to a plastic state and under heavy pressure the two metals are welded together.

The Porto-Spot toggle tyne lever holds metal under maximum pressure. As the handle is squeezed shut, the automatic switch applies the high amperage.

Specifications of the new Model 275 follow: 220–240 v., 50- to 60-cycle, single-phase, 50-amp. fuse recommended. Draws current only when handle is squeezed shut. Spot welds mild and stainless steels up to $^1/_8$ in. combined thickness. New 6-in. two-in-one arms and set of four long-life electrodes. Two 45 degree and two 90 degree electrodes. Ten-foot flexible power cable with ground wire, less plug.

Marquette's new Porto-Spot Welder is listed by Underwriters' Laboratories, Inc., and carries a one-year guarantee against defective materials and workmanship.

For further details write to Marquette Mfg. Co., Minneapolis, Minn.

FOR WELDING AND CUTTING

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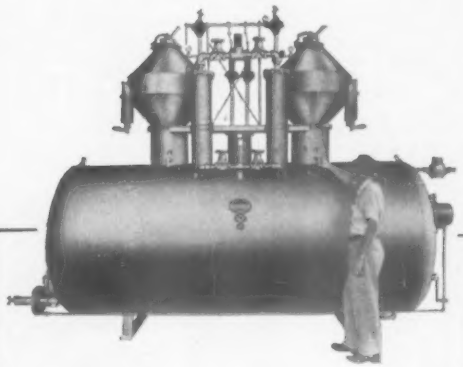
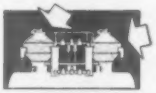
...AND YOU'LL SAVE UP TO 75% OF YOUR PRESENT COST OF ACETYLENE WITH THE VIRTUALLY AUTOMATIC

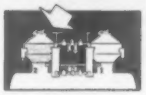
SIGHT FEED MODEL A-TWIN GENERATOR



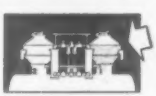
...AND THIS IS HOW



Two hoppers supply the carbide—each operates independently of the other. Start service by filling hoppers, simultaneously metering required amount of water into tank.



When hopper No. 1 is empty, meter fresh water into tank. Hopper No. 2 automatically goes into service. Automatic drain valve opens to release excess water and residue.



Refill hopper No. 1 . . . and acetylene production goes on continuously, without waste of acetylene through purging. No loss of time handling cylinders in and out of plant.

Yes, you'll save *plenty* with the convenient, dependable Model A-Twin . . . as much as 75% of your present cost for acetylene. Write or call today for Catalog 250-N.

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113	200	288	373	650	1000	1350	1700
125	213	300	388	700	1050	1400	1750
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163	250	338	500	850	1200	1550	1900
175	263	350	550	900	1250	1600	1950
188	275	363	600	950	1300	1650	2000

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Welder's Goggle

A new welder's goggle, featuring removable and adjustable binder-type leather side shields, is announced by American Optical Co., Southbridge, Mass.

The new goggle can be adjusted for perfect fit and maximum comfort by loosening the endpiece screws. By removing the endpiece screws, side shields can be taken off for cleaning, sterilizing or replacing. The goggle, series 3081A, replaces AO's 3081 welder's goggle, the company states.

The side shields of the new goggle are made of soft leather, providing greater comfort and increased protection against heat, harmful light and flying particles. The cylinder bridge and reinforcing bar are also covered with leather.

The company also announces that the side shields are available for its No. 3080 welder's goggle.

Head Mixing Cutting Torch

A new oxyacetylene cutting torch with improved balance, comfort and durability has been developed by Dockson Corp., Detroit.

The Model "D" Hi-Speed Cutting Torch mixes the oxygen and acetylene gases at the head, instead of in the center block. The Dockson company has taken advantage of the forward weight to give their new torch better balance. This balance and a total weight of only 39 oz. makes the Model "D" an especially easy torch for long, steady work.

The lightweight Model "D" torch is capable of cutting any weight from light gage to 10-in. steel. Head and valve blocks are of die-forged bronze. Tubing is seamless—cupro-nickel for high-pressure oxygen, bronze for low-pressure and fuel lines. Pure copper tips in sizes 0 through 8 have 4 or 6 precision-drilled preheat orifices.

The customary cone-shaped, tapered seat on the tips is eliminated in favor of carefully machined flat-on-flat coupling of tip and seat. As long as the seats are clean, this coupling is foolproof and leakproof.

High pressure valves are vastly improved in Model "D" Dockson Cutting Torches. Special, long-life valve stems have been installed and are permanently press-fitted to the handles. Improved, self-sealing, impregnated washers replace ordinary packing and the high-pressure seats are located in a position that makes them much easier to replace.

For complete facts, contact the Dockson Corp., 3839 Wabash Ave., Detroit 8, Mich.

All Plastic Goggle

The General Scientific Equipment Co. has announced a plastic, lightweight goggle (GS No. 100 Clear, GS No. 200 Green) which affords wide angle vision and may be worn over prescription glasses. One-piece construction with molded rubber binding to fit natural contours of face. The elastic head band insures a snug fit and all day wearing comfort.

For use against flying particles, sparks, splashes, spot welding, chips, dust, glare—in countless jobs in factories, foundries, shops, laboratories, mines and quarries.

GS No. 100 Clear Goggles cost $1.50 each. Style Gs No. 200 Green, $1.75 each. Discounts in quantities. For complete information or trial order, write to General Scientific Equipment Co., 2700 W. Huntingdon St., Philadelphia 32, Pa.

Improved Types of Flux

New improved types of Solar Flux aimed at cutting costs and improving quality in any fusion welding process on corrosion- and heat-resistant metals have been announced by Solar Aircraft Co., of San Diego.

Tractor Shoes Serve Longer

WHEN YOU...

REPAIR WORN TRACTOR GROUSERS

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U.S. Patents 1,876,738—197,167—2,021,945

11% - 13½% Manganese-Nickel Steel

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Radiographs showing welds in gas tanks. Lower radiograph shows acceptable tank weld.

These radiographs show the welds in propane gas tanks. The upper discloses a lack of fusion and heavy gas porosities. Out of a lot of several hundred tanks, Radiography showed a dozen to be hazardous—twelve potential accidents that were prevented.

Because Radiography can prove the soundness of welds it is opening new fields to welders in manufacturing pressure vessels and in other applications where welding was once barred, it is now an accepted procedure.

This is why Radiography can help you build your business as well as earn a reputation for highly satisfactory work.

If you would like to know more about what it can do for you in your own work, discuss it fully with your x-ray dealer.

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The precision performance of a two-stage RegO Regulator is especially desirable for piped distribution systems and other applications where large volumes of high pressure gases must be controlled accurately.
Two-Stage Regulation Gives You Plus Performance!
Constant delivery pressure regardless of drop in pressure at the inlet . . . Patented design incorporates nozzle-type first stage counterbalanced by stem-type second stage . . . Triple action cartridge filter eliminates troubles usually caused by rust, dust or dirt.
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PIONEER AND LEADER IN THE DESIGN AND MANUFACTURE OF PRECISION EQUIPMENT FOR USING AND CONTROLLING HIGH PRESSURE GASES

The various Solar fluxes are combinations of compounds used to remove surface oxides and prevent oxidation of parts during the welding cycle, which in turn minimizes chipping, grinding, and finishing. They also control the penetration of the weld by permitting higher welding temperatures without "burn-through." They are recommended for all corrosion- and heat-resistant alloys such as stainless steel and superalloys.

The four types of Solar Flux now available are:

Type 16 GH for oxyacetylene welding, particularly of 18–8 stainless steels. Applied to back of seam.

Type 16 for use as a back-up material on lap seams in metallic arc welding. May be used also in gas butt welding when joining materials of dissimilar thicknesses.

Type B for inert gas-shielded arc welding (helium or argon), for atomic hydrogen welding and for metallic arc butt welding. Also suitable for oxyacetylene butt welding. Applied to underside of seam. Primarily for stainless steels.

Type I for oxyacetylene, inert gas-shielded arc, metallic arc and atomic hydrogen welding of Inconel and other high nickel or cobalt alloys such as S-816 Hastelloy C, L-605, N-155, Vitallium and other alloys which melt at slightly lower temperatures than 18–8 stainless steels.

Employment Service Bulletin

Positions Vacant

V-259. Excellent opening for a Graduate Engineer with a background of basic welding processes and a working knowledge of Metallurgy. Position in an Engineering Laboratory of a large concern in Chicago, Ill. Involves the development of welding procedures and processes for ferrous and nonferrous materials. In reply state complete qualifications and salary desired.

V-260. Radiologist required by North East Coast Engineering Firm. Must be experienced in industrial X-ray technique, and conversant with requirements of Lloyds, A. P. I. and A.S.M.E. codes. Permanent position, good prospects. Apply stating qualifications and experience, salary required. Quote ref. "R."

V-261. Recent Graduate Engineer or Metallurgist. Experience in all welding processes to head up welding laboratory to develop manufacturing processes, welding equipment and tooling for manufacturing use. Excellent opportunity with a company that is a leader in the welding of high-temperature alloys.

SECTION ACTIVITIES

prepared by C. M. O'Leary

Arizona

The members and guests of the Arizona Section met October 17th in the Aluminum Room of the Hotel Westward Ho.

Following the dinner, a survey was made by J. August Rau who presided in the absence of the Section Chairman, Arthur Tesmer, of the members present as to their individual preference for types of programs. Many helpful suggestions were received and noted by the Program Committee and all agreed it was very interesting as well as informative.

For the technical portion of the meeting sound films were shown through the courtesy of the Standard Oil Co. on the many features involved with the all-welded oil pipe line recently built in Saudi Arabia. The magnitude of the project, not only in construction but in personnel and administrative problems, was impressed on all present.

The meeting was adjourned by Mr. Rau at 10.00 P.M.

Boston

The regular monthly meeting of the Boston Section was held on October 8th at the Graduate House, M.I.T., Cambridge, Mass.

After a sociable half hour with cocktails, the meeting, the first one of the 1951–52 season, commenced with dinner at 6 P.M. in the Campus Room.

After dinner the Tennessee Gas Transmission Co. furnished a movie, "Gas Goes to Market." E. E. Miller, Vice-President and Chief Engineer of North Eastern Gas Transmission Co., gave a very interesting talk on the construction problems, design and operation of the natural gas pipe lines that are spreading out all over the country. The subject was of special interest to the Boston Section because a gas line is crossing New England, bending out in many directions on its way to Boston and outlying towns. The Section was disappointed because William H. Law of Oklahoma Contracting Co. was unable to come to the meeting and give his scheduled talk on the engineering details.

The regular monthly meeting for November was held on the 5th with an attendance of 79 at dinner and 115 at the meeting.

After dinner, L. I. Dexter gave a short talk about his trip to the Annual Meeting in Detroit. This was followed by a movie "Rendezvous in a Reef" with underwater pictures of marine life in a bay among the Islands of the West Indies.

Co-speakers at the technical session were Chet Rober, Superintendent of the Welding Div. and Jimmy Walse, Welding and Sequence Engineer of the Welding Div. of the Bethlehem Fore River Shipyard, Quincy, Mass.

The speakers were intensely interesting because their talk was on low-hydrogen electrodes in ship construction. Mr. Rober talked about the steady growth of welding in ship construction with the increase of the use of higher strength steels and the low-hydrogen electrodes. Mr. Walse gave a fine talk on the procedures used with this electrode. His talk was very practical and was followed by a long question session.

Bridgeport

The October dinner meeting of the Bridgeport Section was held on the 11th in the Conti Room of Rapp's Restaurant, Shelton, Conn. Cocktails were served from 6:30 to 7:00, followed by dinner.

A coffee talk was given by William Snow, Personnel Director of the Metropolitan Body Co., Bridgeport. He is also chairman of the Y.M.C.A. 1951 Membership Drive. The subject of Mr. Snow's talk was, "Why the 'Y.'" Now celebrating its 100th Anniversary, Mr. Snow touched on the high lights of the growth of the "Y" in the United States since its beginning. It was pointed out that the "Y" was one of the best influences in training children to become the leaders of tomorrow and should be supported by everyone.

The technical speaker of the evening was N. F. Kiernan, District Sales Manager of the Metal and Thermit Corp., who gave a very timely talk on the training of new welders for production welding. Mr. Kiernan has been associated with welding for over 20 years and his talk proved very interesting as the need for good welders in defense work is very acute at the present time.

A discussion followed Mr. Kiernan's talk and many problems of training new welders were brought to light.

The Bridgeport Section has a number of members in the valley area. The officers for the year are: *Chairman*, G. F. Mulligan, A. B. King Co., North Haven; *Vice-Chairman*, J. E. Creel, Peabody Engrg. Co., Stamford; *Secretary*, W. A. Seymour, Farrel-Birmingham Co., Ansonia; *Treasurer*, R. A. Lalli, R. A. Lalli Co., Bridgeport; *Program Chairman*, J. J. Powers, The Producto Machine Co., Bridgeport; *Membership Chairman*, A. A. Young, A. B. King Co., North Haven; *Technical Representative*, J. R. Skibo, Farrel-Birmingham Co., Inc., Ansonia; *Chairman, Executive Committee*, H. Grosberg, Farrel-Birmingham Co., Ansonia.

Chicago

The September 21st meeting was held in the Peoples Gas Light and Coke Co. Auditorium. Dinner in Burke's Grill preceded the meeting.

The meeting consisted of a question-and-answer period with cash prizes. Moderator was A. F. Chouinard of the National Cylinder Gas Co. Judges were L. S. McPhee, Whiting Corp.; R. P. Monroe, National Cylinder Gas Co.; J. M. Parks, Armour Research Foundation, and E. A. Sirabian, American Electric Fusion Corp.

The October 12th meeting and dinner were held in the same place as above.

T. B. Jefferson, Editor of *The Welding Engineer*, was the speaker at the technical session. Mr. Jefferson presented a clear-cut talk on "Applied Welding Engineering." An A.W.S. film on the same subject was shown.

Preceding the technical session, a movie "Wings Over France" was shown.

Cleveland

The Allerton Hotel will continue to be the meeting place of the Cleveland Section, according to John B. Auston, Chairman. This year, however, both dinners and meetings will take place in the Mather Room.

Dinners will be served at 6:30 P.M. in the Mather Room. Dinner tickets should be purchased from the cashier ($1.75). Everyone eating must have a ticket. After dinner, coffee talk and announcements will be made. A 10-minute recess will precede the technical program which will begin promptly at 8 P.M.

A joint meeting with the Society of Naval Architects and Marine Engineers was held on October 10th at the Allerton Hotel. Technical Chairman for this meeting was Kent Thornton of the American Ship Building Co.

Coffee speaker was James M. Dawson, Economist, whose subject "A Crystal Ball Look at the Price Level" was very well received.

Technical speaker was John L. Horton, Marine Superintendent, Cleveland-Cliffs Iron Co. Mr. Horton told the story of the *Cliffs Victory*, the first all-welded Great Lakes iron ore carrier. Mr. Horton briefly summarized the development of the *Cliffs Victory* and described the conversion of a 455-ft., ocean-going Victory ship to the 620-ft. iron ore carrier. Mr. Horton's talk was illustrated with slides.

An attendance of 109 were at dinner and 120 at the technical session.

Colorado

The October 1st dinner meeting was held in Cunningham's Restaurant, Denver, with an attendance of 86 at dinner and 97 at the technical meeting. This was a joint meeting with the American Society of Civil Engineers.

Speaker at the technical meeting was Martin P. Korn of Giffels & Vallet, Inc.,

Associated Engineers and Architects. Mr. Korn's talk on "Adventures in Rigid Frame Design" was illustrated with slides.

Columbus

Regular monthly meeting of the Columbus Section was held on Friday, October 12th, at the Riverside Restaurant, Columbus, Ohio.

Speaker was William Greene, Assistant to the Manager, Metallurgical Process Divison, Air Reduction Co., Inc., Murray Hill, N. J. Mr. Greene's talk on "Physical Phenomena in Inert-Gas-Shielded Arcs," supplemented a color film on some pertinent physical information about electric arcs in inert gases, to show why the types of beads differ with different shield gas or wire and plate material in the Aircomatic process. He explained the shape of penetration patterns in both argon and helium in both the Aircomatic and Heliweld processes. He discussed the forces of electromagnetic origin in the electric arc and the part they play in transfer, arc stiffness and penetration patterns. The talk was illustrated with slides.

Dallas

The October 24th meeting was held in the Lone Star Gas Bldg. Auditorium. Dinner at Brockle's Restaurant preceded the meeting.

An illustrated talk was presented by H. L. Howard and W. P. Clark on "Hard Facing by the Spray Process and Use of Flame to Make a Bond."

Following the technical session a film showing the Southwest Conference Football High Lights of 1950 was presented.

Refreshments were served at the conclusion of the meeting.

Dayton

L. D. Richardson, Regional Manager, Eutectic Welding Alloys Corp., gave a very interesting talk on "Tool and Die Salvage with Low-Melting Nonfusion Filler Metals." Because of the critical shortage of tungsten in the country today, the salvage of tools is of paramount importance.

Mr. Richardson touched on the basic theory behind the eutectic rods—that of surface alloying instead of surface adhesion.

He then followed with a practical discussion of welding the various types of ferrous and nonferrous tools. Equal stress was put on the use of correct rods and correct techniques in using these rods.

Following the talk Mr. Richardson showed an excellent group of slides illustrating the various types of tool repairs.

The above was presented at the October 9th meeting held at the Engineers' Club, Dayton, Ohio. An Executive Committee dinner meeting in the private dining room of the Y.M.C.A. preceded the technical meeting.

Houston

The Houston Section held its October dinner meeting on the 25th at the Ben Milam Hotel, Houston, Tex.

One of its own members, Henry L. Howard, Wall Colmonoy Corp., gave an extemporaneous talk on "Hard Facing by Spray Welding." As an indication of the interest in the subject the meeting was attended by 75 members and guests, some of whom came as far distant as 90 miles.

Mr. Howard, in conjunction with W. P. Clark, Vice-President and Sales Manager of the Wall Colmonoy Corp., showed slides illustrating procedures and character of work applicable to "Spray Welding." After this introduction, a question-and-answer period was held. This was followed by a live demonstration of hard facing applied by the "spray-welding" process. The demonstration answered any remaining questions and evoked considerable interest and favorable comment.

At this meeting the Houston Section invited as their guests two college students—one from Rice Institute and the other from the University of Houston. Both students, seniors in engineering, enjoyed the program and were able to gain an insight into the welding industry that they would not have otherwise had. The project of student guests has received splendid support from the members and it is planned to invite at least three students to each meeting hereafter. In addition to the two schools mentioned, it is planned to invite a student from Texas A. & M., College Station, to the next meeting.

At the conclusion of the program a Directors' meeting was held to discuss an invitation, received from the Engineers Council, for the Houston Section to sponsor one or more 15-minute television programs. The Section was complimented by such a request and a committee is being formed to make necessary arrangements.

Indiana

Regular monthly meeting was held on October 25th with a tour through the Guide Lamp Div. of the General Motors in Anderson, Ind.

Dinner was held in the company cafeteria of the Guide Lamp Div. F. J. Ruda welcomed the guests and gave a brief résumé of Guide Lamp operations. There was an attendance of 74 at dinner and tour.

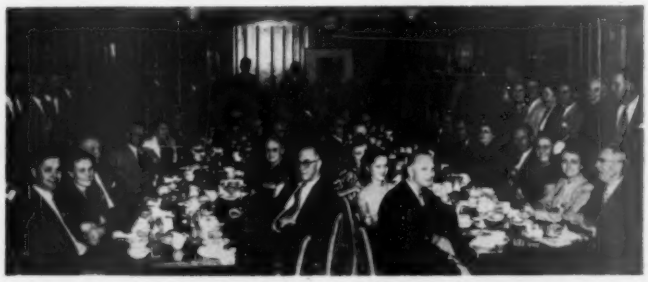
Kansas City

A dinner party for members, wives and guests was held on September 20th at Fred Harvey's, Union Station, Kansas City, Mo. Coffee speaker was Ernest Mehl, Sports Editor, Kansas City *Star*.

The regular monthly meeting was held on October 4th at Fred Harvey's.

Martin P. Korn of Giffels & Vallet, Inc., Associated Engineers and Architects, presented an excellent, extemporaneous talk on "Adventures in Rigid Frame Design."

Recently Indiana Section took advantage of the courtesy of the Stewart-Warner Corp. of Indianapolis to set up a colorful Technical Literature Display of A.W.S. publications in the Cafeteria of the South-Wind Division of that company



Kansas City Section Dinner Party

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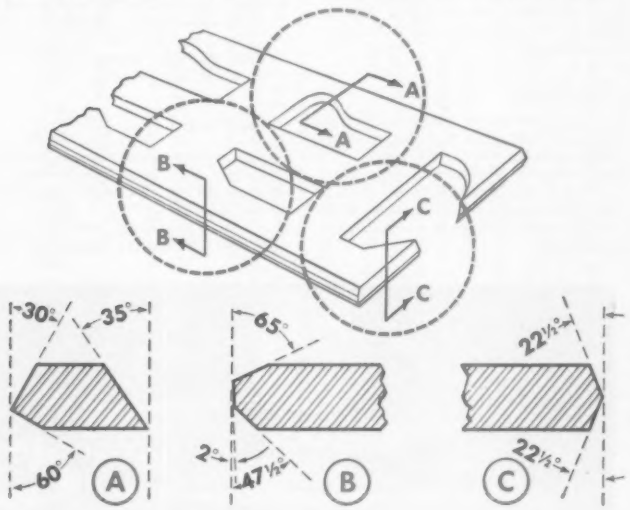

You can quickly see the tremendous savings effected by the Acetogen Process when applied to a complete fabricating job. We *don't* need expensive grinding machines or operators, we *don't* spend extra hours grinding plate edges to tolerances. We pass on *to you* a saving in both time and money!

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Send us your drawings, sketches, or blueprints *now* for any fabricated work you have, and we will promptly quote price- and time-schedules. Our organization has full security clearance to contract for defense work through the Department of the Army, Philadelphia Ordnance Division. Let Acetogen take your fabricating problems off your hands! *Write today!* Acetogen Fabricators, Inc., Room 822, Commercial Trust Building, Philadelphia 2, Pa.

Originators of precision flame-cutting

ACETOGEN FABRICATORS, INC.

Lehigh Valley

Regular monthly dinner meeting was held on October 1st at the Hotel Bethlehem, Bethlehem, Pa.

Coffee speaker was H. O. Hill of the Bethlehem Steel Co. and Past-President of the A.W.S. Mr. Hill gave an illustrated talk on how the standardization of welding symbols was set up through the work of the Welding Society.

L. P. Elly (center) chairman of the Lehigh Valley Section, AWS, discusses some of the finer points of welding with J. F. Lincoln (left) President of the Lincoln Electric Co., and H. O. Hill, past-president of the AWS

Speaker at the technical meeting was James F. Lincoln, President of The Lincoln Electric Co., Cleveland, Ohio. Mr. Lincoln spoke on the highly successful Lincoln Incentive System.

The November 5th meeting was also held at the Hotel Bethlehem.

Lectures and demonstrations on silver brazing and stud welding were the theme of this meeting. R. J. Metzler, Development Engineer for Handy & Harman, spoke on "Design for Silver Alloy Brazing." H. W. Bartley, Manager, Customer Engineering, Industrial Div., for the Nelson Stud Welding Div. of Gregory Industries, Inc., discussed "Split Second Fastening."

Louisville

An unusually interesting discussion of the use of stud welding was made by R. C. Singleton, Manager, Industrial Sales, Nelson Stud Welding Div. of Gregory Industries, Inc., Lorain, Ohio, at the October 23rd meeting.

Mr. Singleton's moving pictures and slides illustrated a number of significant applications such as ordnance construction, railroad, shipbuilding, automotive and other production industries.

Mahoning Valley

A plant visit was made on October 25th to the Cooper-Bessemer Plant (Diesel Engines), Grove City, Pa., with approximately 100 in attendance.

A buffet supper at the Penn Grove Hotel preceded the plant visit.

Maryland

Van Rennsselaer P. Saxe of Saxe, Williar & Robertson, was the guest speaker at the October 19th meeting held at the Engineers Club in Baltimore.

Mr. Saxe made an extemporaneous presentation on the subject "Welded Building Construction," which was illustrated with slides and very interesting.

Milwaukee

The October 26th meeting at the Ambassador Hotel drew a small group of 47 hardy folks. Inclement weather, Marquette University Homecoming and the Joe Louis fight competed with Mr. Jacobsmeyer. The folks who stayed away really missed something.

Lawrence Jacobsmeyer, Executive Vice-President and General Manager of Salkover Metal Processing of Illinois, Inc. (Chicago), was the Technical Speaker. His lecture and slides covered the entire field of copper brazing of light gage metals and alloys. Mr. Jacobsmeyer is an excellent speaker with a wide background of practical experience in this field. His ready replies and practical suggestions to problems in the question-and-answer period pleased the members and friends attending. His table full of samples kept the subject hot for a long time after the meeting adjourned.

New Jersey

The annual picnic which was held at the Pines, Metuchen, N. J., on September 15th, was attended by 326 people. The largest number of prizes ever assembled at a picnic were on hand this year. As a result of the successful handling of the picnic affairs, almost $400 profit was realized on the venture.

Prizes awarded and list of prize donors

The regular monthly meeting was held on October 9th at Essex House, Newark.

Before the technical meeting a 16-mm. film entitled "Green Harvests" was shown through the courtesy of the Weyerhaeuser Timber Co., Washington State. This was an excellent film.

Speaker at the technical meeting was E. B. Lutes of Arcrods Corp., Sparrows Point, Md. Coating materials for 6010, 6011, 6012, 6013, 6015, 6016 and others were described by Mr. Lutes. The effects of these coatings on penetration and fillet shape were described. Finally, the operator's reaction to using the various classifications revealed that the 6012 class is by far the most popular with the welders and about 50% of the electrodes made are of this classification. However, weld quality is apt to be the poorest when using 6012 class as compared with the weld quality using the other classes of electrodes.

Mr. Lutes mentioned the shortage of rutile, the main constituent of 6012 coverings. It was interesting to note that the welding industry uses 65% of all the rutile used, most of which is imported from Australia.

Schedule of meetings for the remainder of the 1951–52 season of the New Jersey Section is as follows:

Dec. 18, 1951—H. C. Boardman, Chicago Bridge and Iron Co., "Interpretation of Codes as Applied to Welded Construction."

Jan. 15, 1952—Willy Ley, Rocket Specialist, "Design and Construction of Modern Rockets," Joint Meeting with A.S.M.E.

Feb. 19, 1952—James F. Lincoln, The Lincoln Electric Co., "The Role of Welding in Industry."

Mar. 18, 1952—To be announced. "Fabrication of High Temperature Piping."

Apr. 15, 1952—To be announced. "Symposium on Cutting of Stainless Steels and Some Nonferrous Alloys."

May 20, 1952—Annual Meeting. Subject to be announced.

New York

The regular monthly dinner meeting of the New York Section for October was held on the 9th at Schwartz's Restaurant, New York City.

Clarence E. Keeting, Assistant Division Engineer, Mechanical Engineering Dept., Consolidated Edison Co. of New York, was the speaker at the technical meeting. Mr. Keetings' subject was "Pipe Welding in Steam Power Generation."

Niagara Frontier

A plant visit to the Buffalo Forge Co. was made from 5 to 6:30 prior to the buffet supper and meeting held at the Sheraton Hotel, Buffalo, on October 25th.

Speaker at the technical meeting was Van Rensselaer P. Saxe, Consulting Engineer on Structural Design and Fabrication, whose subject "Welding in Structural Steel Design and Fabrication" was excellently presented.

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Above is a photo taken at the recent Niagara Frontier Section meeting on September 27th. (Writeup in November Section Activities). Those in photo are, left to right, Clarence E. Jackson, Charles H. Jennings, AWS President, G. Fitch Cady II, Chairman, Niagara Frontier Section, Ogden Mills, a former chairman, T. O'Donnell, Olean Division, Robert Siemer, Secy.-Treas., Niagara Frontier, and J. G. Magrath, National Secretary

Oklahoma City

The October meeting of this Section was held on the 23rd at the Mustang Plant of the Oklahoma Gas and Electric Co. with 50 members and guests attending.

The speaker, Henry L. Howard of Wall Colmonoy Corp., gave a highly interesting and informative talk on hard facing followed by a live demonstration of spray welding. The program was concluded with a tour of the Mustang Plant.

Pascagoula

The Pascagoula Section held its regular monthly meeting on October 3rd at Evangeline Restaurant, Pascagoula, Miss., with an attendance of 50 at dinner and meeting.

Coffee speaker was Earl R. Hammett, Plant Comptroller, Ingalls Shipbuilding Corp., who spoke on the operational conditions at the Yard. Excellent talk.

Speaker at the technical meeting was C. R. Schaeffner, Chief Engineer, Ingalls Shipbuilding Corp., Pascagoula. Mr. Schaeffner presented an excellent paper on the Ingalls Shipbuilding Program.

Peoria

A plant tour through the International Harvester Co., Canton, Ill., was made on October 17th. This was followed by a 30-minute question-and-answer period.

Richmond

The Richmond, Va., Section meets on the third Thursday of the month at Ewart's Cafeteria on 5th St., Richmond, Va., where dinner is served to members and guests.

At the November 15th meeting there was a discussion on the "X-Raying of Welded Seams" by T. Lewis of the Froehling and Robertson Laboratories of Richmond, Va. Mr. Lewis is an X-ray specialist on welding. The firm has a wide reputation as industrial analysts and metallurgists.

In the past the Section has had several good speakers and have been very fortunate in procuring distinguished lecturers.

Rochester

The Rochester Section held its first autumn meeting on October 29th, as the guest of the Gleason Works, located in Rochester, N. Y. A very delicious dinner was served to approximately 85 members in the plant's cafeteria. After dinner, E. B. Gleason was introduced and gave a very interesting review of the history of the Gleason Co. The Gleason Co. is a pioneer in the manufacturing of precision gear cutting machines and related equipment.

Harry Stoler, Chairman of the Rochester Section, thanked the Gleason management for their generous hospitality and cooperation in making this event possible.

The members were divided into small groups, each accompanied by a guide, for the inspection trip.

Saginaw Valley

Plant visits were made to the Dow Chemical Co., Bay City, Mich., and Defoe Shipbuilding Co., Bay City, Mich., on October 11th, with an attendance of 155 for both.

St. Louis

One of the most interesting meetings as well as the best attended was held on Friday evening, October 12th, at the Forest Park Hotel. Members and guests numbered 98 to hear Anton L. Schaeffler of the Allis-Chalmers Mfg. Co., Milwaukee, Wis., present the subject of "Simplified Metallurgy for Welders and Welding Supervisors." Mr. Schaeffler characterized his down-to-earth subject with interesting slides somewhat "Disney-ish" in character, which proved to be a welcome relief from the highly technical and difficult-to-understand graphs and charts usually utilized in subjects of this nature. His talk was well accepted by the St. Louis Section with technician and operator alike departing with a better understanding of methods of overcoming difficulties encountered in the welding of mild steel, high-strength steels, stainless steels and dissimilar metals.

Salt Lake City

A tour was made through the plant of the Chicago Bridge & Iron Co. on October 18th following dinner at the plant. A. H. Drake was in charge of the tour. Very interesting practical demonstrations were shown and explained to groups by special guides, employees of the Chicago Bridge & Iron Co. Eighty-six were present at dinner and 104 attended the tour.

Toledo

The following officers have been elected by the Toledo Section for the fiscal year: *Chairman*, M. W. Eddins, Kaighin & Hughes, Inc.; *1st Vice-Chairman*, George J. Schmitt, Williams & Co., Inc.; *2nd Vice-Chairman*, Harry Hansen, Hans Hansen Welding Co.; *Secretary-Treasurer*, E. L. Brenner, Williams & Co., Inc.; *Chairman, Program Committee*, G. J. Schmitt, Williams & Co., Inc.; *Technical Representative*, Sam Snell, Odland Iron Works.

Washington

September 26th meeting of the Washington, D. C., Section was held at the Pepco Auditorium. Dinner preceded the meeting at O'Donnell's Restaurant.

Speaker at the technical meeting was Paul Ffield of the Bethlehem Steel Co.

Western Massachusetts

The Western Massachusetts Section held its first meeting of the season at Balke's Restaurant, Springfield, Mass.

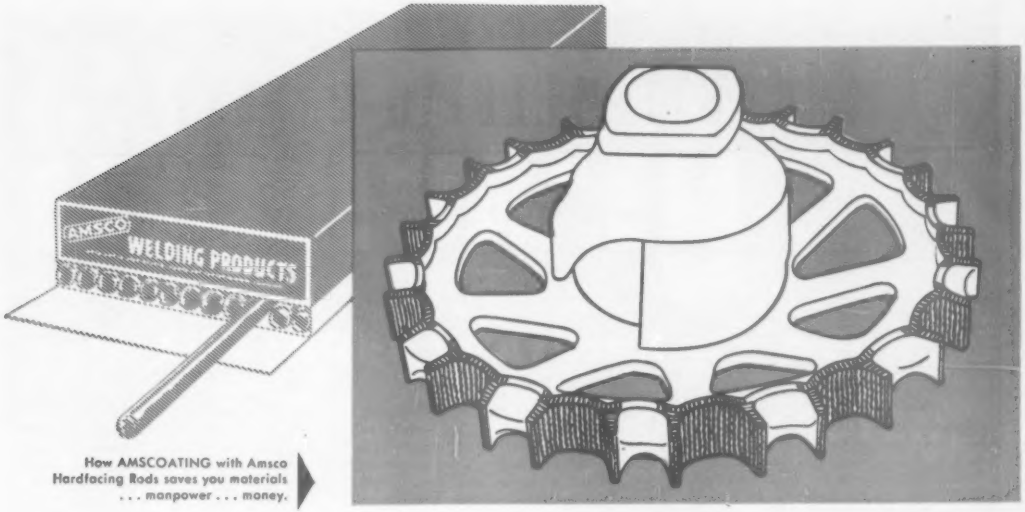
Following the dinner, William Haskell of the Springfield Ordnance District gave a talk on Government Contracts for the small job shops, outlining the procedure that is required for war preparation for defense work.

Mr. Haskell brought out that 98% of the Springfield Ordnance District prime contracts were given to small businesses of 500 or less employees. He also pointed out that all procurements, 67½%, were made by small business and that 13$^{1}/_{10}$% of dollars went to small business for Government Contracts.

Western Michigan

A tour of the Sutherland Paper Co. was made on October 22nd by members of the Western Michigan Section. Several guides divided the group into parties of seven and started at the beginning and took the visitors through the complete process of papermaking—a very interesting tour. Before the tour, a film "History of Papermaking" was shown through the courtesy of the Sutherland Paper Co.

Dinner at the Columbia Hotel, Kalamazoo, preceded the tour.



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abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington 10, D. C.

2,569,030—Preparing Aluminum Welding Wire—Russel V. Vanden Berg, New Kensington, Pa., assignor to Aluminum Company of America, Pittsburgh, Pa., a corporation of Pennsylvania.

This patent covers a method of preparing aluminum wire for use as an electrode in an inert-gas-shielded arc welding process. The method includes the steps of immersing the wire in an aqueous solution of alkali metal zincate and thereafter removing the coating so formed by immersion in an acid stripping solution.

2,569,059—Welded Rivet Construction for Electrical Brushes and Contacts—Melvin O. Huff, Fostoria, and Arthur W. Seidler, Cleveland, Ohio, assignors, by mesne assignments, to Union Carbide and Carbon Corp., a corporation of New York.

This patent relates to a frangible electrical contact brush that has a conductor in electrical contact therewith. A resistance-welded structure is provided and it has an enlarged end portion for bearing against the brush, an intermediate shank portion extending through a hole in the brush and the conductor, and a second enlarged end portion bearing against the conductor. The resistance weld in the structure sets up residual tension to aid in making a good electrical contact between the conductor and the brush.

2,569,211—Welded Bolster Center Brace—Charles M. Wright and Louis G. Miller, Bethlehem, Pa., assignors to Bethlehem Steel Corp., a corporation of Pennsylvania.

A specialized part of a railway car underframe is disclosed in this patent and is formed from a pair of rolled members secured together by welding action.

2,569,304—Cutting Torch Attachment—Melvin C. Gledhill, Las Cruces, N. Mex.

Gledhill's patent relates to an attachment for a cutting torch and it includes a rod that is detachably connected to the cutting tip of a cutting torch at one end of such rod and is secured rigidly to the handle of the torch at its other end. A guide unit is slidably and rotatably mounted on the rod and includes a guide block having a substantially V-shaped groove therein. This guide block is adapted to engage a V-shaped guide bar for guiding the tip of the torch in cutting straight lines.

2,569,476—Arc Welding Apparatus—George G. Landis, South Euclid, and Norman J. Hoenie, Cleveland Heights, Ohio, assignors to The Lincoln Electric Co., Cleveland, Ohio, a corporation of Ohio.

A transformer is covered in this patent and includes a stator body of hollow form having an inwardly directed pole-providing projection and a movable member cooperating with the projection to form a variable magnetic bridge. Primary and secondary windings encircle the stator adjacent the projection thereon. An extension of the stator body encloses a space opposite to the projection and the extension together with either adjacent lateral portion of the stator body provide a flux path equivalent to that provided by the body when encircled by the primary and secondary windings.

2,569,715—Welder's Hood—Howard H. Green, Bardwell, Tex.

Green's patent is on a welder's hood that has a sight opening therein. A window is hinged to the hood for covering the sight opening and chin actuated means control the operation of the window.

2,569,956—Cartouche for Joining Metal Bodies Especially for Light Metals, by Welding—Adolf Schiltknecht, Neuhausen, Switzerland, assignor to Societe Anonyme pour l'Industrie de l'Aluminium, Chippis, Switzerland.

A welding cartridge is disclosed in this patent for welding nonferrous metal bodies. The cartridge has an inner tubular member for closely fitting around the metal bodies to be united and an outer tubular cover member surrounds the inner member and is spaced therefrom with an exothermic reaction mass being enclosed within the space between the inner and outer tubular members. An igniting mixture also is provided as is a tearing-off strip embedded in the igniting mixture for igniting same.

2,570,791—Welded Frame Structure—John B. Grebe, Midland, and Walkley B. Ewing, Grand Rapids, Mich., assignors to Ewing Development Co., Grand Rapids, Mich., a corporation of Michigan.

This patent is on a specialized structural member adapted to engage a panel and it includes a web having a pair of substantially parallel edges. Inwardly curved portions are provided on the parallel edges and are secured together by a welding action.

2,571,313—Welding of Metallic Tips to Metallic Bases—Norman Albert Tucker, London, England, assignor to Johnson, Matthey & Co. Ltd., London, England, a British company.

Tucker's patent is on a method of welding a metallic tip to a metallic base wherein the tip and base are in pressure contact and welding current is passed through such contacting elements to produce melting of metal in at least one of such elements. In this welding action, a resistance of a value for reducing the welding current to a strength adequate only to delay freezing or solidification of the molten metal is inserted into the welding circuit as soon as one of the elements to be welded together moves a predetermined distance toward the other. This passage of reduced strength current in the welding circuit is maintained during a further predetermined amount of relative movement of the elements after which the current is cut off.

2,571,553—Chain Welding Machine—Paul Esser, Koln-Raderberg, and Peter Wilz, Koln-Bayenthal, Germany.

This patent relates to an electric resistance butt-welding machine for chain links.

2,571,684—Gas Shielded Arc Welding Torch—Kenneth C. Craven, Fitchburg, Mass., assignor to General Electric Co., a corporation of New York.

Craven's patent is on a hand torch for welding operations in which a filler wire is fused and added to the weld metal at the point of welding. A wire feeding mechanism is mounted in an enclosure on a rear portion of the handle of the torch. A motor is supported at a point remote from the torch and has a flexible shaft connected to the drive shaft of the feeding mechanism on the handle. A flexible wire guide extends from the handle and receives a filler wire therein from an exterior source of wire.

2,572,084—Welding Electrode Holder Construction—Charles K. Wilson, East Williston, N. Y., assignor to Metallizing Engineering Co., Inc., Long Island City, N. Y., a corporation of New Jersey.

A welding electrode holder is disclosed in the patent and includes an electric coil mounted on the holder in fixed relation to electrode securing means. A magnetizable armature is resiliently mounted for oscillation on said holder

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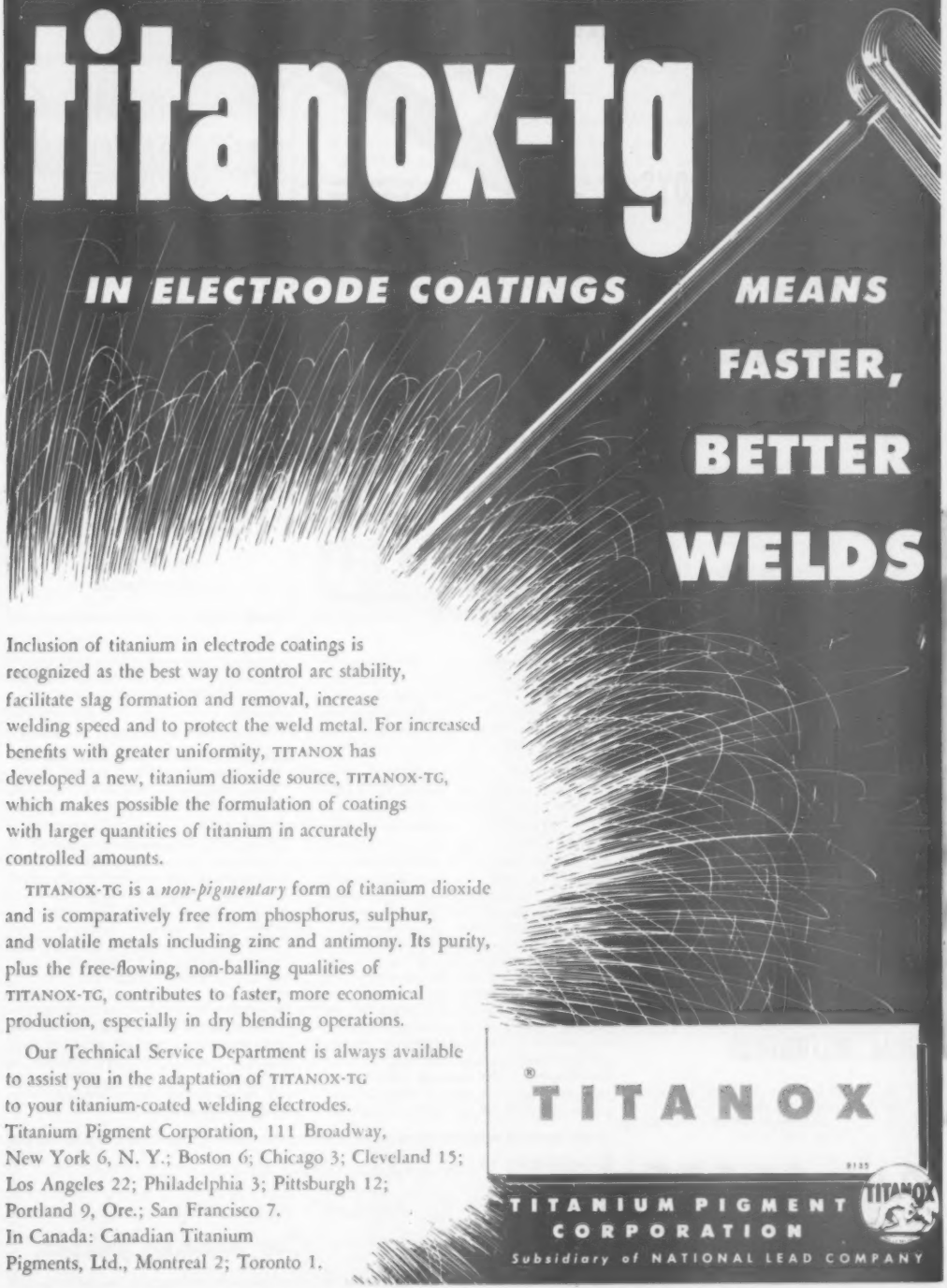

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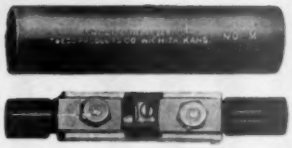

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at pretuned frequencies. The armature is magnetized upon electric impulse energization of the coil for magnetic attraction thereby. The electrode securing means can be oscillated by oscillation of the armature.

2,572,593—Apparatus for Brazing Fins to Tubes—John W. Brown, Jr., Lakewood, Ohio, assignor to Brown Fintube Co., Elyria, Ohio, a corporation of Ohio.

This patented apparatus is adapted to bond an elongate member to the exterior of a tube substantially parallel to the tube axis by fusing a bonding metal on the exterior of the tube. A mandrel is provided on a frame of the apparatus and heating means are provided to heat an annular portion of the tube, while cooling means are also provided to direct coolant against another annular increment of the tube. Means are carried by the frame to hold an elongate member against the exterior of the tube and they engage this member in at least two longitudinally spaced zones. The elongate member and tube are fixed with respect to each other as the assembly of the tube and member are moved with respect to a head carried by the mandrel so as first to heat and then cool successive annular increments of the tube to bond it and the elongate member together.

2,572,796—Welding Method and Apparatus—Harry W. Woodard, Akron, Ohio, assignor to The B. F. Goodrich Co., New York, N. Y., a corporation of New York.

Woodard's apparatus is adapted to weld an article without overheating portions of the article remote from the weld. A bath of cooling liquid is provided and it has a support in the bath below the surface of the liquid to hold the article in the bath with a shallow layer of liquid over the article. The support is connected electrically to one pole of an electric current and a jet nozzle is positioned above the bath and directed at the surface in the region of the desired weld to blow away liquid covering such proposed weld area. A welding electrode connects to the opposite source of electric current and is positioned above the article at the proposed weld area.

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Temperature Distribution During the Flash Welding of Steel

Flashing methods compared on the basis of temperature distribution and how this information may be utilized in selecting flashing variables

by E. F. Nippes, W. F. Savage, J. J. McCarthy and S. S. Smith

Abstract

The flashing portion of the flash-welding process was investigated using S.A.E. 1020 steel in various section sizes. Measured temperature distributions were employed as criteria for comparison of the effect of individual flashing variables for two general types of flashing pattern. Three linear flashing patterns, having constant platen velocities of 0.326, 0.144 and 0.072 in./sec. were studied. Six parabolic flashing patterns, having constant platen accelerations distributed in the range 0.004 to 0.90 in./sec.^{2} were investigated for various initial clamping distances.

Parabolic flashing was found to establish a stable-temperature gradient with 55% less burnoff per specimen than required with linear flashing. Increasing platen acceleration, increasing specimen thickness and decreasing initial clamping distance were shown to produce steeper stable temperature gradients. The secondary welding voltage and the specimen width were shown to have no effect on the stable temperature distribution during flashing.

A flashing parameter was developed permitting comparison of flashing conditions in terms of the temperature distributions produced, and examples are given illustrating how this information may be used in selecting flashing variables.

INTRODUCTION

THE production of flash welds in constructional steels requires that consistent welds of the maximum possible joint efficiency be obtained with a minimum of material loss during welding. In order to attain this goal, a thorough understanding of the contribution of each of the flash-welding variables is essential, and must be intelligently employed in the selection of optimum welding conditions. With these facts in mind, the present investigation of the flash welding of plain carbon and alloy constructional steels was undertaken, financed by the Air Research and Development Command.

In a previous investigation[1] on aluminum alloys, a study of the temperature distribution back of the flashing interface was found valuable in determining the contribution of the individual flashing variables. Since the over-all weld properties reflect the temperature distribution at the instant of upset as well as the effect of the upset variables, a thorough study of the effect of flashing variables on the temperature distribution was undertaken as the first phase of the over-all investigation. This report summarizes the information obtained on the effect of flashing variables on temperature distribution, and will be supplemented at a later date by another report on the contribution of upset variables.

OBJECT AND SCOPE

The object of this investigation was to evaluate the contribution of the flashing variables to the temperature distribution back of the flashing interfaces. Included in the investigation were the effects of:

1. The type of platen time-displacement pattern employed during flashing

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Paper presented at the Thirty-Second Annual Meeting, A.W.S., Detroit, Mich., week of Oct. 15, 1951.

2. The flashing voltage
3. The total burnoff during flashing
4. The initial clamping distance
5. The section size

Two general types of time-displacement patterns were studied; one in which platen motion occurred at a constant velocity, and one in which platen motion occurred at a constant rate of acceleration. The first, or constant-velocity platen motion is hereafter referred to as a linear flashing pattern, while the second, or constant rate of platen acceleration is referred to as a parabolic flashing pattern. Within each general type various velocities or accelerations were employed to determine the influence of these factors.

For the present investigation, only rectangular sections were studied, but it is proposed in the future to extend the work to cover round bar stock.

MATERIAL

Since the thermal and electrical properties of most constructional steels are very similar,[2] the temperature distributions associated with welding these steels should be dependent on the flash-welding variables, and essentially independent of the composition. Therefore, the study of the influence of flashing variables was conducted entirely with A.I.S.I. 1020 steel, hot-rolled, pickled and oiled. Temperature measurements were made in rectangular bar stock of the dimensions shown in Table 1 below. All bar stock was carefully degreased prior to use.

Table 1—A.I.S.I. 1020 Section Sizes

Thickness, in.	Width, in.	Length, in.
0.250	2.00	6.00
0.375	2.00	6.00
0.375	1.10	6.00
0.500	2.00	6.00

In the initial stage of the investigation specimen ends were beveled at 2 degrees, measured from a normal to the rolled surface, but a modification of the welding equipment later permitted the bulk of the work to be performed with no edge preparation.

WELDING EQUIPMENT

This investigation was performed using a Federal, 300-kva. hydraulically operated flash welder with power obtained from a single-phase alternator driven by a three-phase synchronous motor. Due to the marked drooping characteristic of the generator, some difficulty was experienced initially in starting flashing, but a unique modification of the sequence mechanism on the flash welder later permitted flashing up to $^1/_2$- x 2.00-in. specimens with no difficulty. A complete description of this equipment will be found in Appendix 1 to this report, but the following summarizes the important features incorporated in the new sequence-control mechanism.

Flexibility—With the modified sequence control it is possible to select any platen acceleration rate from 0.004 in./sec.^{2} to 0.10 in./sec.^{2} by means of a setting on a calibrated dial. In addition, a constant, slow velocity of approach is provided up to the initial instant of closure. The first pulse of flashing current serves to initiate the platen acceleration to provide the desired parabolic flashing pattern.

Reproducibility—The sequence cam shaft is driven by an electronically controlled d.-c. motor with a speed regulation of $\pm 1\%$ provided by a specially designed reference voltage supply. This permits consistent duplication of flashing patterns with less than 2% variation.

Good Starting Characteristics—Despite the poor voltage regulation provided by the power source, no difficulty was experienced in starting flashing in up to 1.0-sq.-in. sections without any special end preparation. This is a result of the adjustable approach velocity feature which allows selection of very slow approach velocities until actual closure is made. With other types of sequence control, the approach velocity is usually dependent upon the actual flashing pattern, and it is therefore difficult to start fast-flashing operations. With the present modification, the velocity of approach is independent of the flashing pattern, and starting presents no difficulty. In addition, field forcing is provided on the welding generator to permit increasing the voltage at the start of flashing for a short interval of time. The duration of the application of field forcing is adjustable so that normal flashing voltage can be restored as soon as practical under a given set of conditions.

GENERAL PROCEDURE

In order to evaluate the effect of welding variables on the temperature distribution back of the flashing interface, over 300 pairs of specimens were flashed, each with several recording thermocouples attached. Initially, four recording thermocouples were imbedded in each specimen, but later work was performed using seven thermocouples per specimen in order to obtain more temperature data from each run. At least four duplicate runs were made at each set of flashing conditions in order to permit elimination of random errors from the final data.

Specimen and Thermocouple Preparation

One specimen of each pair employed in the flashing investigation was prepared to receive thermoucouples by drilling a series of 0.052-in. diameter holes at appropriate locations. The holes were positioned relative to one another with the aid of a specially constructed jig, and a depth step was used to locate the bottom of each hole. Figure 1 shows a typical radiograph indicating

Fig. 1 Typical radiograph of weld specimen

the exact location of the seven thermocouple holes in a typical specimen. It should be noted that the bottom of the first hole is approximately 0.10 in. from the end of the specimen, and that the bottom of each successive hole is located approximately 0.10 in. farther from the initial flashing interface. By drilling the holes at an angle of 45 degrees and positioning them as indicated in Fig. 1, an unobstructed heat-flow path was provided between the bottom of each hole and the flashing interface. Radiographs similar to that shown in Fig. 1 were taken of each prepared specimen, and the location of the thermocouples relative to the initial flashing interface measured from the radiograph to the nearest 0.01 in.

Two types of recording thermocouple were employed during the investigation. For locations where the peak temperature attained was in the neighborhood of 2000° F., 0.010-in. diameter iron-constantan-duplex thermocouples were employed. For locations nearer the flashing interface, where higher temperatures were encountered, 0.012-in. diameter, chromel-alumel-duplex thermocouples were used. The thermocouples were prepared by cross-wire welding the small-diameter glass- and asbestos-insulated wires at one end of a 7-in. length of the duplex wire. The overlapping ends of the two wires were then trimmed back to the weld to provide a small hot junction at the weld. The hot junction of the thermocouple was then securely welded to the bottom of one of the 0.052-in. diameter holes in the specimen. A 300-mfd. bank of condensers, previously charged to 300 v., was discharged through the thermocouple-specimen contact in order to produce an intimate bonding between the thermocouple hot junction and the bottom of the thermocouple hole.

Instrumentation

After attaching the thermocouples to the specimen, and placing the specimen in position in the welder, an electrical-continuity check was performed to make sure the thermocouple was still in intimate contact with the specimen. The output of each thermocouple was then connected to a recording galvanometer in a 14-channel Consolidated recording oscillograph, using a suitable series resistance to limit the galvanometer deflection. The basic sensitivity of the recording galvanometer being 0.03 ma./in. at recording distance, a series resistor large enough to make minor changes in thermocouple resistance negligible was employed in all cases.

A platen-movement trace, which was used to determine the material consumption after any time interval, was obtained in the following manner. A 20-ohm linear potentiometer with a pinion gear mounted on the shaft was attached to the fixed platen. A rack, attached to the movable platen, engaged the pinion, and thus actuated the movable contact of the potentiometer. By connecting a 1.5-v. d.-c. potential across the potentiometer, a voltage proportional to the relative position of the two platens was obtained. This voltage signal was connected to a recording galvanometer in the Consolidated oscillograph and a continuous record of platen position was thus provided on every record.

Timing lines were provided on the records produced by the Consolidated oscillograph at intervals of 0.01 sec. Every tenth timing line, representing a time interval of 0.10 sec., was automatically made of greater density to facilitate analysis of the records.

The welding current was recorded with the aid of a General Electric split-core current transformer, connected in the primary of the welding transformer. The output of this transformer was fed into a recording element in the Consolidated oscillograph with the aid of a suitable shunt.

Flashing Procedure

It should be noted that, in this investigation of the flashing variables, only the flashing cycle was experienced by the specimens. Since the initiation of upset is not controlled by the flashing cam, maximum available flashing distance was utilized, and therefore all flashing was continued longer than necessary for successful flash welding.

In the investigation of each flashing variable, sufficient specimens were flashed to provide for elimination of random errors, and, in some cases, more than the usual four duplications were made in order to obtain sufficient data for the temperature distribution. This was the case early in the investigation when only four thermocouples were attached to each specimen, but usually four duplicate runs were sufficient after the seven-thermocouple specimen was adopted.

Figure 2 shows a typical oscillograph record obtained from an actual flashing run. The temperature rise associated with each thermocouple location may be seen as a movement of the thermocouple traces toward the center of the record. The direction of displacement of some of the thermocouple traces was reversed in order to facilitate reading of the records. The advance of the platen is indicated by a displacement of the travel trace upward toward the center of the record. The current record is located at the center as indicated, and the transverse, 0.10-sec. timing lines may also be seen in the figure.

RESULTS

The investigation of the flashing process was divided into two major portions, according to the type of time-displacement pattern employed during flashing. Two types of platen-movement patterns were used, namely,

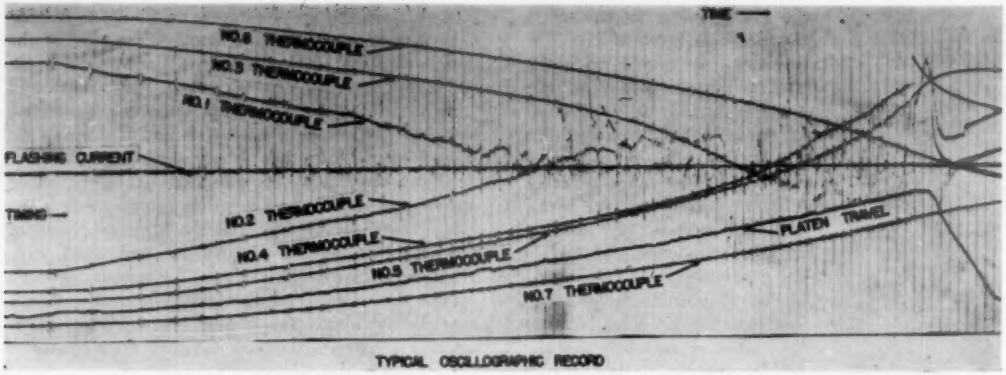

Figure 2

linear and parabolic, in order to determine the more effective method. With the linear flashing pattern, the platen advanced with a constant velocity throughout the flashing operation, giving a platen displacement which bore a linear relationship to the flashing time. With parabolic flashing pattern, the platen advanced with a constant rate of acceleration. It can be shown mathematically* that this corresponds to a linear change in velocity with time, or more conveniently that the platen displacement plotted as a function of time yields a parabola.

Figure 3 compares the flashing patterns employed in this investigation. Three linear velocities and six different parabolic patterns were studied. Table 2 summarizes the flashing conditions shown in Fig. 3.

Table 2—Summary of Flashing Patterns Studied

Type flashing pattern	*Flashing velocity, in./sec. at platen*	*Flashing acceleration, in./sec.² at platen*
Linear (slow)	0.074	...
Linear (medium)	0.144	...
Linear (fast)	0.326	...
Parabolic 1	...	0.004
Parabolic 2	...	0.010
Parabolic 3	...	0.020
Parabolic 4	...	0.040
Parabolic 5	...	0.100
Parabolic 6	...	0.90

* If a = acceleration = a constant, v = instantaneous velocity = $\int a\,dt = at$, where t = time in seconds. y = platen displacement = $\int v\,dt = \int at\,dt = {}^1/_2\,at^2$, which is an equation for a parabola.

Treatment of Data

From the oscillographic records obtained from each run, temperatures at each of the thermocouple locations were obtained, together with data on the platen position as a function of time. In order to eliminate time as a parameter, and permit comparison of specimen temperatures on the basis of the amount of burnoff, the temperature data were then plotted as a function of burnoff per specimen. It was assumed that both specimens burned off at the same rate, and therefore the per-specimen burnoff was taken as one-half the total platen movement at any given instant. Figure 4 shows a typical plot of temperature in ° F. at each of the seven thermocouple locations as a function of burnoff in in./spec. The data shown in Fig. 4 were obtained from one of four duplicate runs made with an initial clamping distance of 1.20 in., using 0.375- x 2.00-in. specimens, flashed with a platen acceleration of 0.004 in./sec.² Similar plots were made from the other three duplicate runs as the initial step in determining the temperature distribution.

From each set of four such plots, knowing the thermocouple loca-

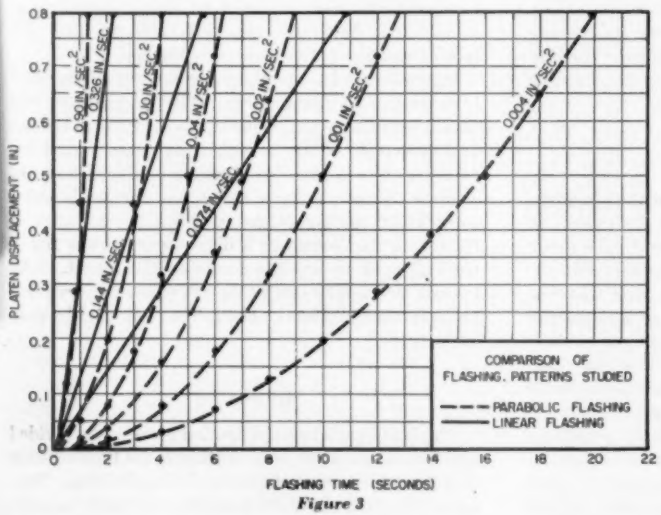

Figure 3

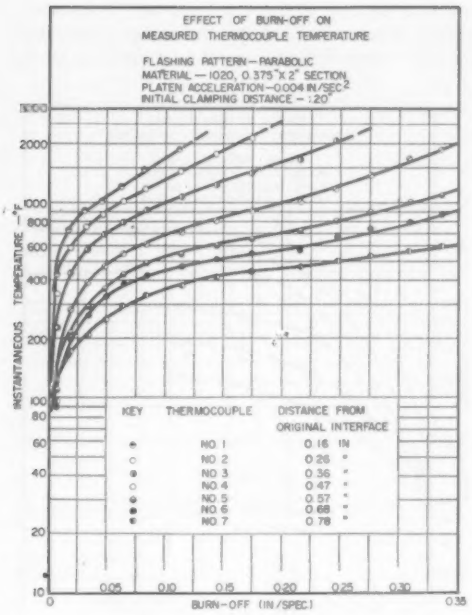
EFFECT OF BURN-OFF ON
MEASURED THERMOCOUPLE TEMPERATURE
FLASHING PATTERN — PARABOLIC
MATERIAL — 1020, 0.375"x 2" SECTION
PLATEN ACCELERATION — 0.004 IN./SEC.²
INITIAL CLAMPING DISTANCE — 1.20"
INSTANTANEOUS TEMPERATURE — °F.
BURN-OFF (IN./SPEC.)
KEY THERMOCOUPLE DISTANCE FROM ORIGINAL INTERFACE
NO. 1 0.16 IN
NO. 2 0.26 "
NO. 3 0.36 "
NO. 4 0.47 "
NO. 5 0.57 "
NO. 6 0.68 "
NO. 7 0.78 "

Figure 4

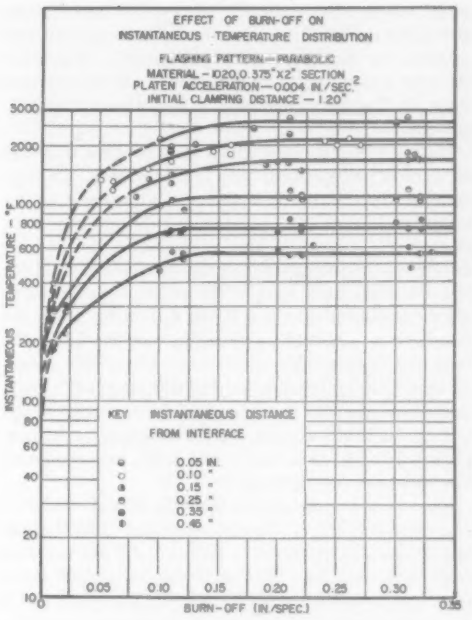

Figure 5

tions with respect to the original flashing interface, it was possible to obtain a graphic summary of the temperature distribution for each combination of flashing variables. Figure 5, which was obtained from Fig. 4 and its three companion plots, shows how the temperature of each of six different distances from the instantaneous flashing interface depends on the burnoff. Figure 5 is taken as a typical example in order to explain the technique involved. From Fig. 4, it may be seen that the thermocouple originally located 0.26 in. from the initial flashing interface reached a temperature of 2000° F. after 0.16 in. had been removed by flashing. After 0.16 in. of burnoff, however, this thermocouple was located 0.10 in. from the instantaneous position of the flashing interface, and a point is therefore found in Fig. 5 at 2000° F. for the 0.10-in. position, at 0.16 in. burnoff. Similarly, after 0.26 in. burnoff, the thermocouple located 0.36 in. from the initial flashing interface reached the 0.10-in. position, and indicated a temperature of 2200° F. This process is repeated, and the data obtained plotted until a family of curves can be constructed as shown in Fig. 5, indicating the influence of the amount of burnoff on the instantaneous temperature at various locations in the specimen.

For every set of flashing conditions studied, the steps outlined above were repeated in order to obtain a plot similar to Fig. 5. By comparing the plots obtained in this manner, a comprehensive picture of the influence of various flashing variables has been obtained. The influence of the independent variables on the temperature distribution has been used as a basis for comparison throughout this investigation.

Linear Flashing

Constant platen velocities of 0.326, 0.144 and 0.074 in./sec. were employed with an initial clamping distance of 2.78 in. in order to determine the effect of platen velocity on the temperature distribution during linear flashing. Figures 6–8 show the temperature distributions in 0.250- x 2.00-in. specimens, for constant platen velocities of 0.326, 0.144 and 0.074 in./sec., respectively. Each figure shows the temperature as a function of burnoff at several positions relative to the instantaneous flashing interface, obtained by the method outlined previously for Fig. 5. For example, it may be seen by inspection of the upper curve in Fig. 6 that flashing the first 0.20 in. from the specimen raised the temperature at a point 0.05 in. from the interface from 80 to 1400° F. Furthermore, after flashing 0.45 in. from the specimen, the temperature 0.05 in. from the flashing interface remained essentially constant at 1850° F. during the next 0.25 in. of burnoff. In the same way, change in temperature with burnoff at locations 0.10, 0.15, 0.25, 0.35 and 0.45 in. from the instantaneous flashing interface may be seen from the other five curves in Fig. 6. Figures 7 and 8 present similar data for platen velocities of 0.144 and 0.074 in./sec., respectively.

It should be noted that, in Figs. 6–8, the temperature all along the specimens rose continuously during the

initial 0.45 in. of burnoff per specimen, but the temperature at the indicated locations then remained essentially constant for the next 0.25 in. of burnoff. Since this behavior was found to be common to all flashing patterns, the flashing process may be treated as a two-stage process.

During the first stage, which comprises the first 0.45 in. burnoff per specimen with linear flashing, the temperature distribution is changing continuously as the temperature rises at all points along the specimen axis. During this stage, the heat produced at the flashing interface is traveling through the specimen toward the water-cooled copper jaws of the welder, thus establishing a temperature gradient in the specimen. Since the temperature gradient is changing continuously, the initiation of upset should not occur during this period. If upset were initiated during the first stage of flashing, minor variations in the amount of burnoff prior to upsetting would be accompanied by variations in the temperature distribution, and would result in inconsistent forging action during upset.

The second stage of the flashing period, which is characterized by a stable-temperature distribution, begins after approximately 0.45 in. burnoff per specimen with linear flashing. During this period, which exists for the next 0.25 in. of burnoff under the linear flashing conditions studied, the temperature gradient exists unchanged.

The temperature distribution during this second stage was found to depend on the platen velocity employed, as indicated in Fig. 9. Figure 9 is a plot of stable temperature as a function of distance from the instantaneous flashing interface, and shows the stable temperature gradients obtained during second-stage flashing, for the

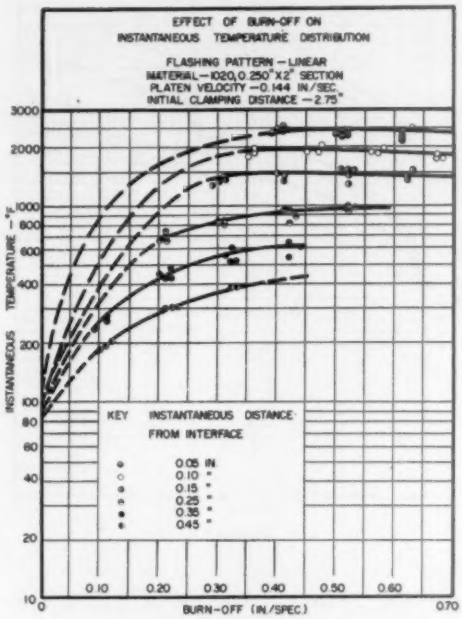

Figure 7

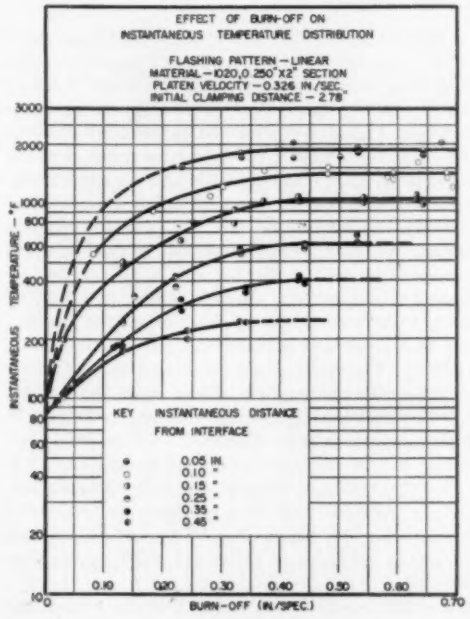

Figure 6

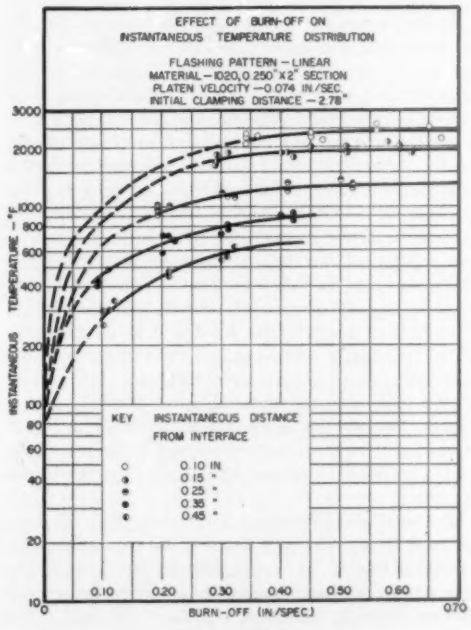

Figure 8

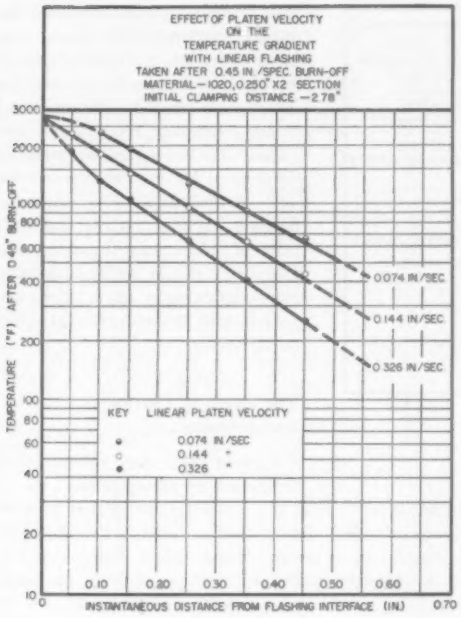

Figure 9

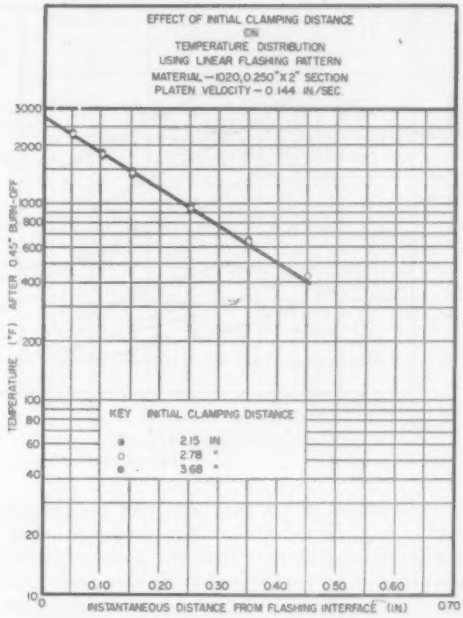

Figure 10

three platen velocities studied. It should be noted that the lower the platen velocity, the higher is the stable temperature at any given distance from the flashing interface. For example, it may be seen that at a point 0.10 in. from the instantaneous flashing interface, the stable temperature was 2300° F. with a platen velocity of 0.074 in./sec., 1800° F. with 0.144 in./sec. and 1300° F. with 0.326 in./sec. Investigation showed that the stable temperature gradients indicated were consistently obtained when duplicate runs were made at the same velocity.

Figure 10 shows the results of a study of the effect of initial clamping distance on the temperature distribution for linear flashing. Changing the initial clamping distance from 3.68 to 2.15 in. produced no significant change in the temperature distribution. This may be verified by inspection of Fig. 10, where the stable temperature gradients for 0.144 in./sec. platen velocity, and initial clamping distances of 2.15, 2.78 and 3.68 in. were plotted, and found to superimpose. Although it is possible that clamping distances less than 2.15 in. would affect the temperature distribution, further studies were discontinued for reasons which will become apparent in a later section on parabolic flashing.

Figure 11 summarizes the effect of platen velocity on the temperature distribution for linear flashing, and although it was obtained for an initial clamping distance of 2.78 in. it has been found to hold for initial clamping distances at least as low as 2.15 in. This figure was obtained by plotting stable temperatures at six locations shown previously in Figs. 6–8 for 0.250-x 2.00-in. specimens as a function of the platen velocity, the latter being plotted on a logarithmic scale. From this plot, it is possible to select a platen velocity which will produce a desired stable temperature gradient in the specimens. For example, suppose it is desired to utilize an upset of 0.25 in./sec. and that, in order to obtain satisfactory forging action, it is further desired that all 0.25 in. of material be above 1300° F. at the instant of upset. From Fig. 11, a horizontal line at 1300° F. would intersect the 0.25-in.-position curve at a point corresponding to a platen velocity of 0.068 in./sec. Therefore, by utilizing a platen velocity of 0.068 in./sec., and flashing at least 0.45 in. from each specimen to insure obtaining the stable, stage-two temperature distribution, the conditions would be satisfied. For comparison, suppose only 0.10 in. of material was desired above 1300° F., by reference to Fig. 11, it may be seen that in this case a platen velocity of 0.37 in./sec. would be required.

Returning to the significance of the stable temperature distribution, it has been pointed out that initiating upset during stage-one flashing could lead to inconsistencies in weld performance because minor variations in the amount of burnoff during this stage appreciably change the temperature distribution. On the other hand, during stage-two flashing, variations in the amount of burnoff prior to upset, such as are often encountered in practice, would not influence the temperature distribution. During stage-two flashing, a balance exists between the heat reaching a particular location from the flashing interface, and the heat leaving

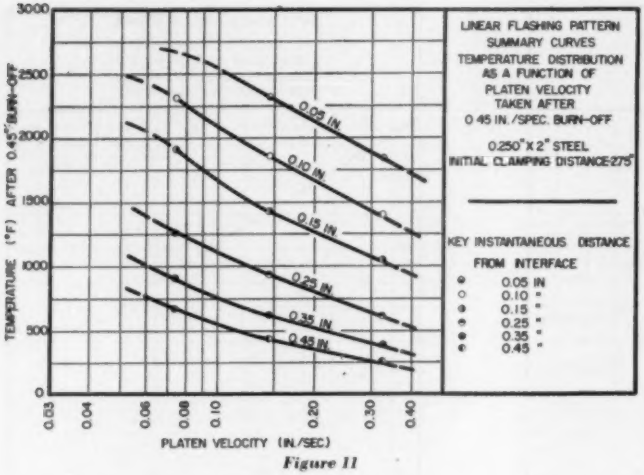

Figure 11

in the direction of the jaws, and thus the temperature at a given location remains unchanged. Since a point a fixed distance from the flashing interface must migrate toward the jaws at the same rate as does the flashing interface, the temperature distribution, though stable, is a dynamic heat-flow problem and is difficult to analyze mathematically. However, investigation has indicated that the relatively low thermal conductivity of the steel is a contributing factor in the type of gradient produced.

Re-examination of Fig. 9 reveals, for instance, that the slope of the three temperature gradients shown is essentially the same, except for the region near the flashing interface. With the fast platen velocity of 0.326 in./sec., heat tends to be produced at the interface faster than it can be conducted away by the surrounding material, and therefore the temperature gradient is steeper near the interface. On the other hand, with the slow platen velocity of 0.074 in./sec., the temperature gradient is less steep near the interface, indicating that the heat is being produced at too slow a rate to maintain the steep temperature gradient in this high-temperature region. In the case of the intermediate velocity of 0.144 in./sec., however, the temperature gradient appears to approximate closely the exponential distribution which would be expected. This is evidenced by the fact that the temperature vs. position curve is nearly a straight line on a semilogarithmic plot such as Fig. 9.

Parabolic Flashing

Because a relatively large amount of burnoff per specimen was found necessary to establish a stable temperature gradient with linear flashing, it was decided to investigate the temperature distributions produced by parabolic flashing patterns. In a previous investigation,[1] involving structural aluminum alloys, parabolic flashing was shown to be satisfactory, since the slow starting velocity decreased the energy requirements during the initial portion of the flashing period. As the temperature of the flashing interfaces increased with continued flashing, however, it was shown previously that the power requirements diminished for a given linear velocity of flashing. The parabolic flashing pattern, with its constant rate of platen acceleration, was found to increase the flashing velocity continuously at a rate compatible with this reduction in power requirement.

The Effect of Platen Acceleration

Figures 12–17 show the measured temperature distributions as a function of burnoff per specimen for platen accelerations of 0.004, 0.010, 0.020, 0.040, 0.100 and 0.90 in./sec.^{2}, respectively. These plots were obtained in a manner similar to that previously explained for Fig. 5, using an initial clamping distance of 1.50 in. with 0.250- x 2.00-in specimens. Upon comparison of these figures with Figs. 6, 7 and 8, previously presented for linear flashing, it is immediately apparent that the parabolic flashing patterns reduced the duration of stage-one flashing. In all cases, in Figs. 12 through 17, the stable stage-two temperature distribution was obtained after a maximum of 0.20 in. of parabolic flashing per specimen. This represents a reduction of 55% in the burnoff requirements when compared to the 0.45 in. per specimen required with linear flashing. Since comparable reductions in the burnoff requirements were observed under all conditions of parabolic flashing studied, further investigation of linear flashing was discontinued, and the balance of the investigation devoted to parabolic flashing. The practical significance of such a reduction in burnoff requirements should be immediately evident, particularly where the more expensive alloy steels are concerned.

Returning to Figs. 12 through 17, comparison of these figures reveals that increasing the platen acceleration steepens the temperature gradient. Figure 18, which was obtained from Figs. 12 through 17 by plotting the stable temperature as a function of position relative to the flashing interface, compares the temperature gradients for the six platen accelerations studied. It may be seen from Fig. 18 that the faster the platen acceleration, the lower is the temperature at a particular location relative to the instantaneous flashing interface. For example, at 0.10 in. from the flashing interface the stable, stage-two temperature was 2300° F. with 0.004 in./sec.^{2} platen acceleration, 2070° F. with 0.010, 1700° F. with 0.020, 1320° F. with 0.040, 970° F. with 0.100 and 720° F. with a

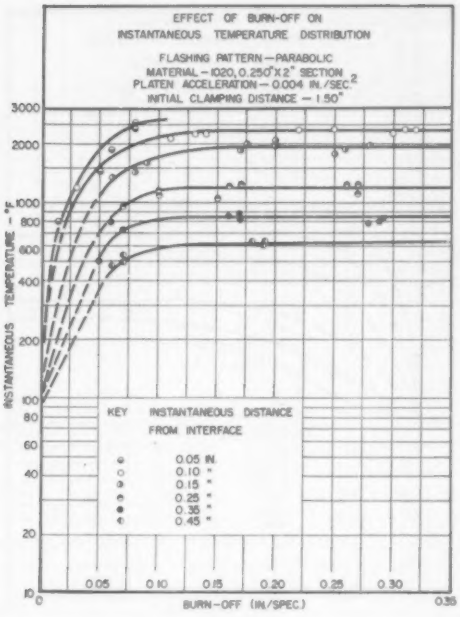

Figure 12

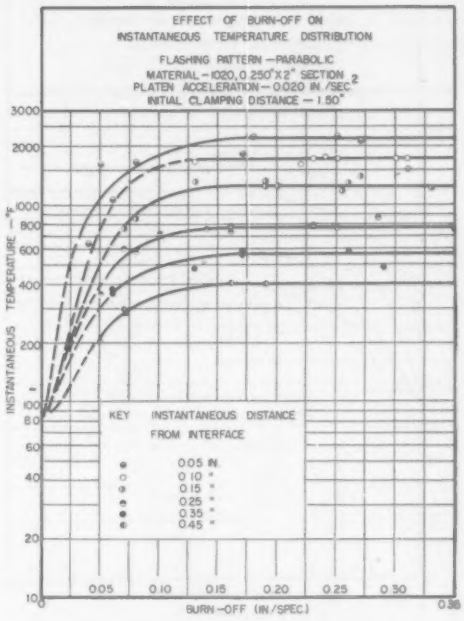

Figure 14

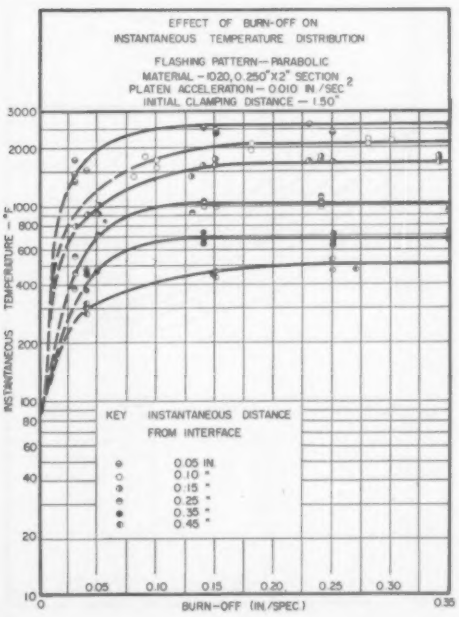

Figure 13

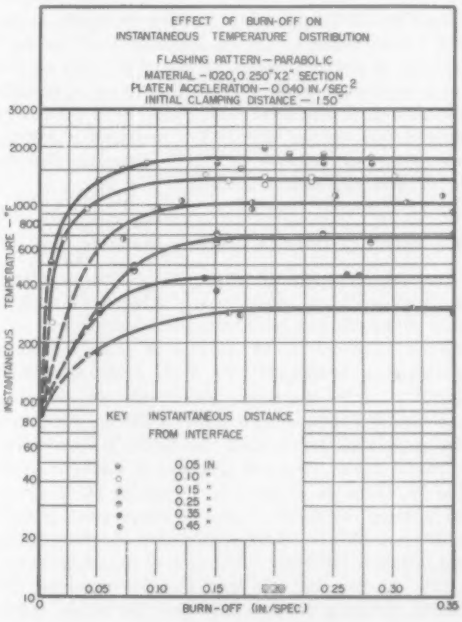

Figure 15

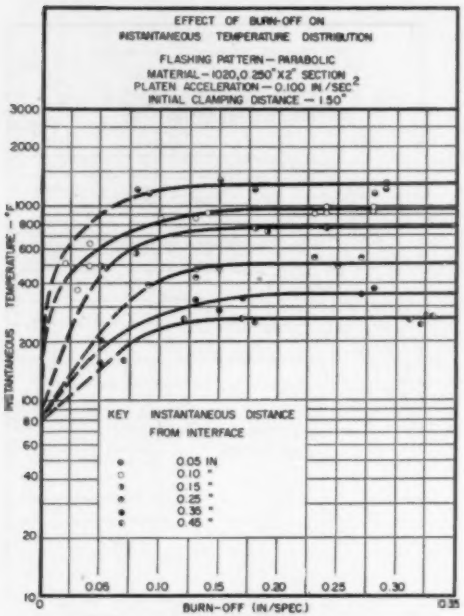

Figure 16

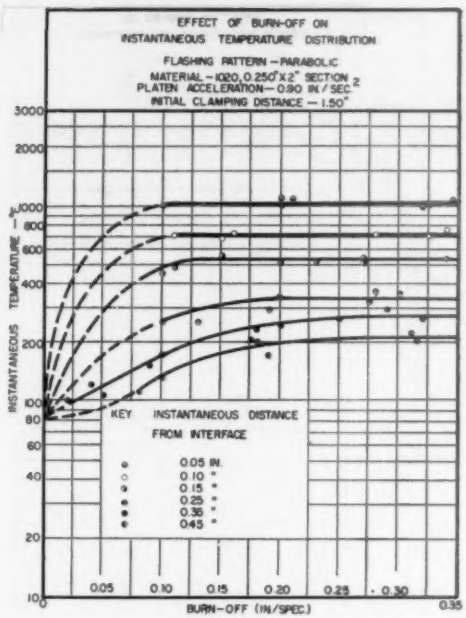

Figure 17

platen acceleration of 0.90 in./sec.^{2}

Figure 19 summarizes the effect of platen acceleration on the temperature distribution during parabolic flashing for 0.250- x 2.00-in. specimens with an initial clamping distance of 1.50 in. This figure was obtained from Figs. 12 through 17 by plotting the stable, stage-two temperatures at the six indicated locations as a function of platen acceleration, the latter being plotted on a logarithmic scale. From Fig. 19, it is possible to select a platen acceleration which will produce a desired temperature distribution in 0.250- x 2.00-in. specimens with a 1.50 in. initial clamping distance by methods previously discussed for Fig. 11.

The Effect of Initial Clamping Distance

In order to make the above information on platen accelerations more generally applicable, an investigation of the effect of initial clamping distance was conducted. Figures 20, 14, 21 and 22 show the effect of clamping distances of 1.20-, 1.50-, 1.80- and 2.78-in. initial clamping distances, respectively, on the temperature distribution with 0.250- x 2.00-in. specimens and a platen acceleration of 0.020 in./sec.^{2} The effect of initial clamping distance is summarized in Fig. 23, which was obtained from Figs. 20, 14, 21 and 22 by plotting the stable, stage-two temperature at each of the indicated locations as a function of initial clamping distance, the latter being plotted on a logarithmic scale. As may be seen from Fig. 23, increasing the initial clamping distance increases the stable, stage-two temperature at any particular location with parabolic flashing. For example, at a distance of 0.05 in. from the instantaneous flashing interface, the stable

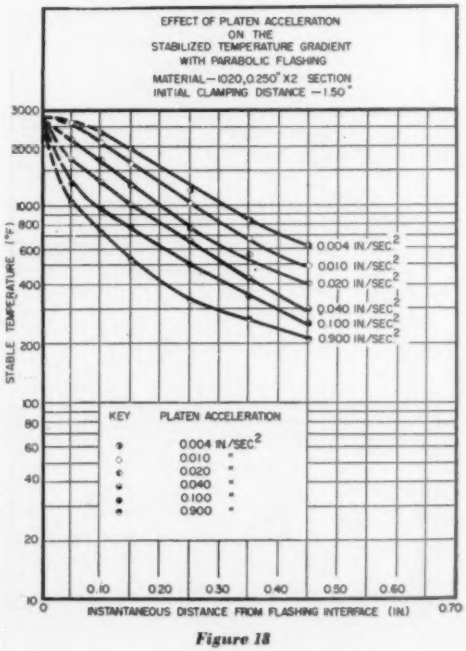

Figure 18

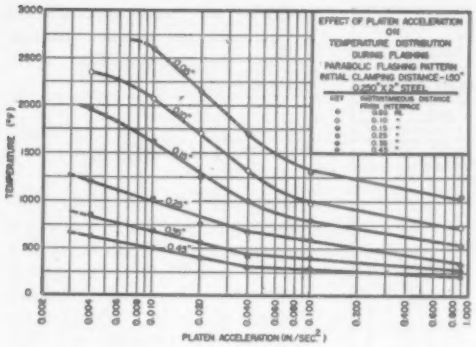

Figure 19

temperature with 0.020 in./sec.² platen acceleration is 2100° F. with an initial clamping distance of 1.20 in., 2175° F. with 1.50 in., 2250° F. with 1.80 in. and 2400° F. with a 2.78-in. initial clamping distance. This behavior reflects the combined effect of the increased length of the heat-flow path from the interface of the jaws of the welder, and the limiting influence of the thermal conductivity of the steel. In other words, increasing the length of the heat-flow path from the flashing interface to the jaws tends to increase the temperature at a particular location by restricting the heat flow away from that point. The effect varies according to the location, however, being more pronounced the longer the heat-flow path to the jaws, as may be seen by further inspection of Fig. 23. For example, it may be seen that the slope of the 0.05 in. location curve in Fig. 23 is noticeably steeper than

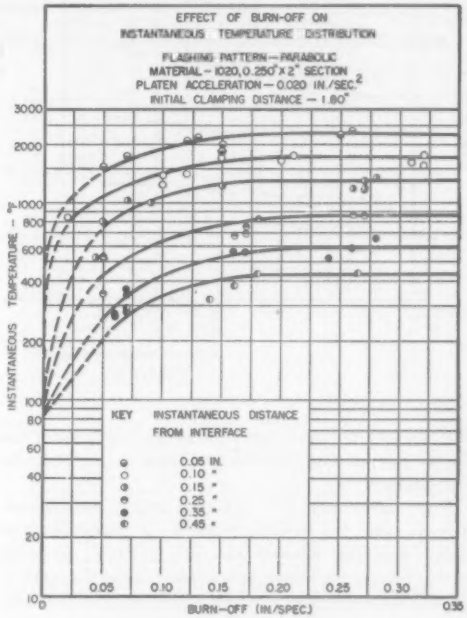

Figure 21

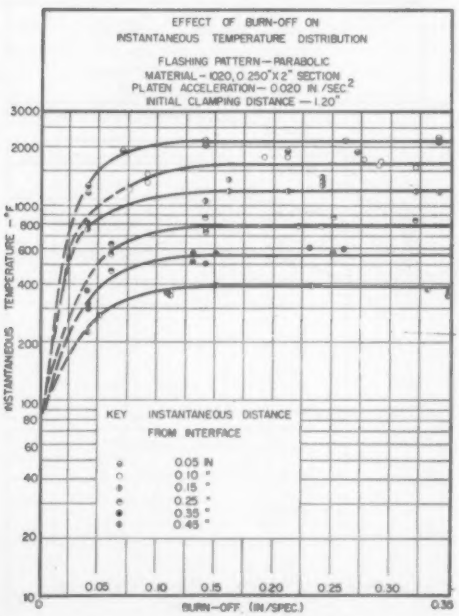

Figure 20

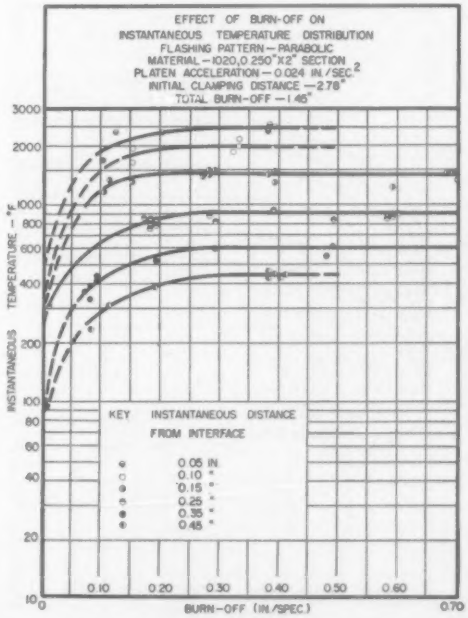

Figure 22

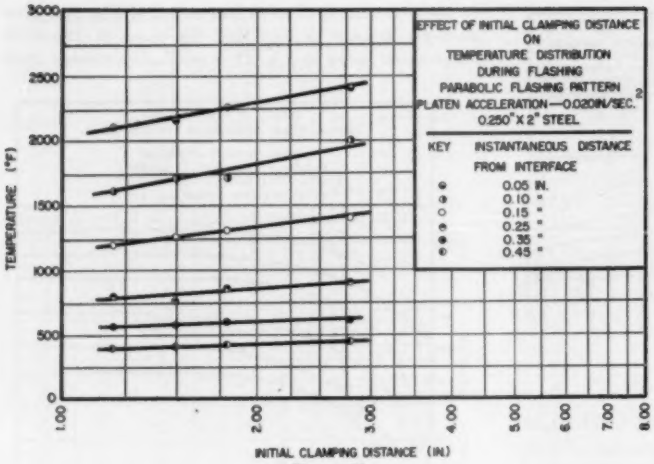

Figure 23

that for the 0.45-in. curve, indicating the greater influence of clamping distance on points nearer the flashing interface.

From this study, it is apparent that, if localization of heat near the flashing interface is important, the initial clamping distance should be reduced in order to shorten the heat-flow path to the jaws of the welder. On the other hand, if a slightly wider region of material above some arbitrary forging temperature is found desirable, this can be accomplished by increasing the clamping distance, without changing the platen acceleration.

The Effect of Section Size

Figures 24, 25 and 26 show the temperature distributions obtained in specimens 0.250 x 2.00 in., 0.375 x 2.00 in. and 0.500 x 2.00 in., respectively, with an initial clamping distance of 1.80 in., and a platen acceleration of 0.010 in./sec.^{2} Figure 27 was obtained from Figs. 24, 25 and 26 by plotting the stable, stage-two temperature at the indicated locations as a function of specimen thickness. It should be noted from Fig. 27 that below 0.375-in. section thickness the change in temperature distribution is slight, as evidenced by the shallow slope of the position curves in this region. However, a more pronounced change in the temperature distribution is produced by increasing the specimen thickness to 0.500 in. In general, it is evident that increasing the specimen thickness decreases the stable temperature found at a particular location with respect to the flashing interface.

Figure 28 shows the temperature distribution ob-

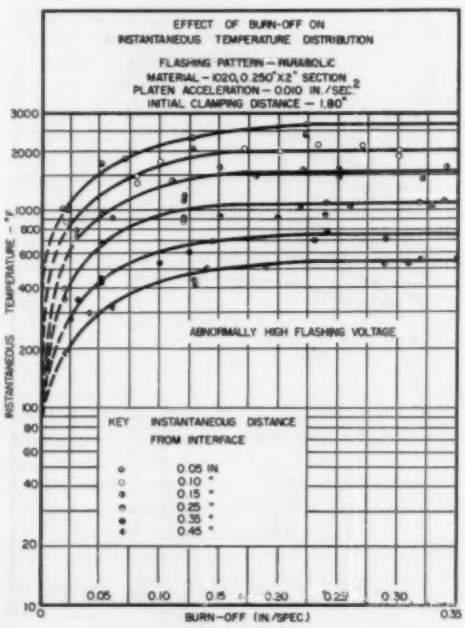

Figure 24

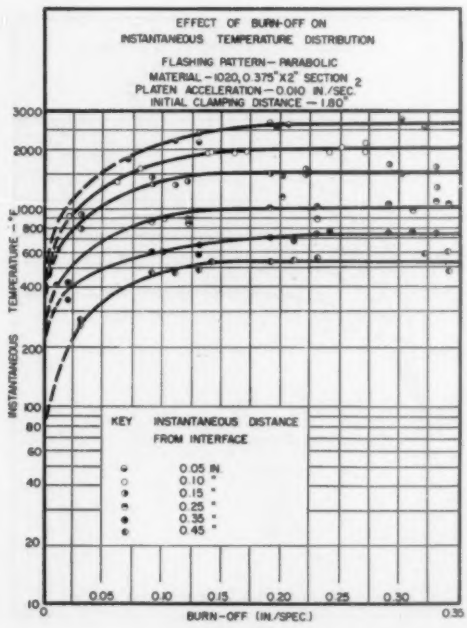

Figure 25

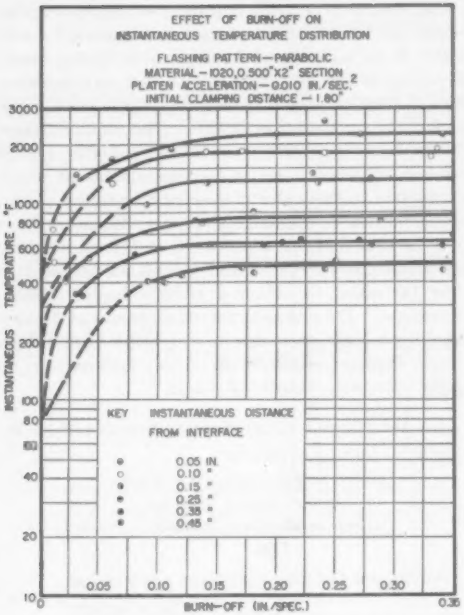

Figure 26

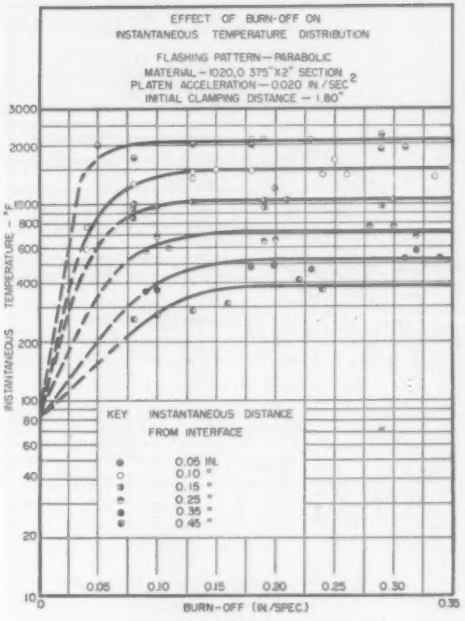

Figure 28

tained by flashing 0.375- x 2.00-in. specimens with an initial clamping distance of 1.80 in. and a platen acceleration of 0.020 in./sec.^{2} Comparison with the temperature distribution shown in Fig. 29, obtained by flashing 0.375- x 1.10-in. specimens under the same conditions, reveals no significant change in temperature distribution attributable to section width. From this study it was concluded that, although specimen thickness influences the temperature distribution, the width of the specimen is not important.

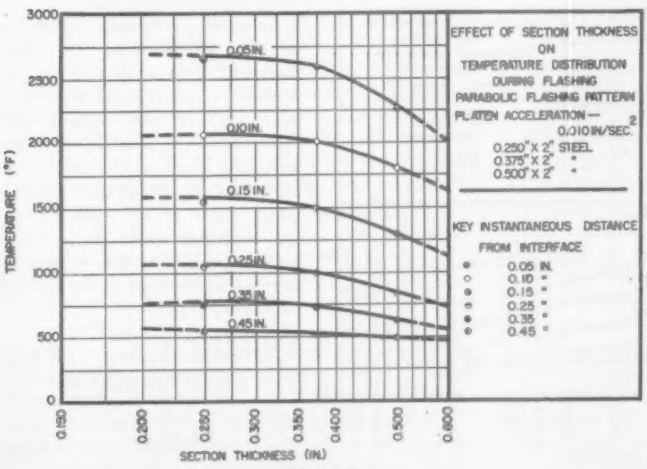

Figure 27

The Flashing Parameter for Parabolic Flashing

Treatment of all the data obtained from the parabolic flashing study revealed that the temperature distributions could be related by means of an empirical flashing parameter. This parameter was developed to contain the three major flashing variables found to influence the temperature distribution, and is defined as follows:

$$\text{Flashing parameter} = \frac{\text{platen accel. (in./sec.}^2) \times \text{sect. thickness (in.)}}{\text{initial clamping distance (in.)}} \quad (1)$$

The parameter was set up in this way since it was found that increasing section thickness and increasing platen acceleration influenced the temperature distribution in the same direction, whereas changing the initial clamping distance had the opposite effect.

Figure 30 is a summary showing the stable, stage-two temperature data for all parabolic flashing conditions studied, plotted as a function of the flashing parameter, the latter being plotted on a logarithmic scale for convenience in reading. It should be noted that a single curve showing the stable, stage-two tem-

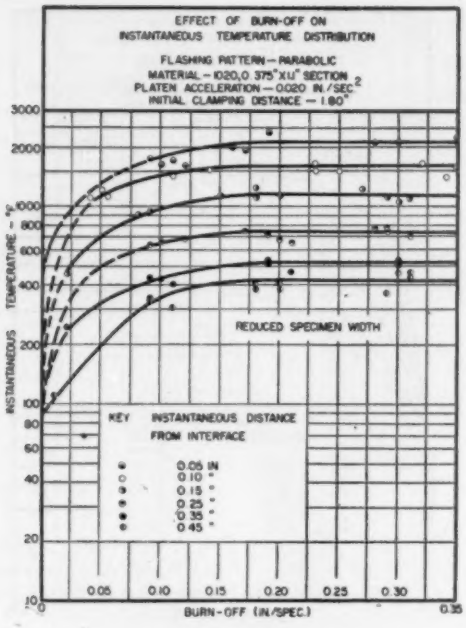

Figure 29

perature may be drawn for each of the six positions relative to the flashing interface. Table 3 summarizes the conditions studied, and the values plotted in obtaining Fig. 30. It will be noted that, when plotted as a function of the flashing parameter, all the stable-temperature data fit the indicated position curves within the limits of the experimental error.

By means of Fig. 30, it is possible to select parabolic flashing conditions which will produce a desired stable temperature distribution. For example, suppose that a flash weld is to be made in 0.400-in. thick rectangular stock, and that 0.15 in. of material is desired above 1300° F. to insure good forging action during upset. Referring to Fig. 30, it may be seen that, at a temperature of 1300° F., the 0.15-in. position line has a value of flashing parameter of 0.0029. The required value of the flashing parameter is therefore 0.0029, and it remains to select a set of flashing conditions which correspond to this value of flashing parameter. From the definition of flashing parameter, Equation 1, it may be seen that, for a particular thickness, both the initial clamping distance and the platen acceleration may be varied to obtain a given value of flashing parameter. For example, two suitable sets of flashing conditions have been determined below, one for an initial clamping distance of 1.5 in., and one for an initial clamping distance of 1.2 in.

1. Assuming an initial clamping distance of 1.5 in.,

$$0.0029 = \text{flashing parameter} = \frac{\text{platen acceleration} \times \text{thickness}}{\text{initial clamping distance}} = \frac{\text{platen acceleration} \times 0.400}{1.50}$$

Solving for the required platen acceleration,

$$\text{platen acceleration} = \frac{1.50 \times 0.0029}{0.400} = 0.011 \text{ in./sec.}^2$$

for an initial clamping distance of 1.50 in.

2. Assuming an initial clamping distance of 1.20 in.,

$$\text{platen acceleration} = \frac{1.20 \times 0.0029}{0.400} = 0.0087 \text{ in./sec.}^2$$

Therefore, 0.15 in. of material above 1300° F. would be obtained by either of the above sets of conditions, namely, using a platen acceleration of 0.011 in./sec.² and an initial clamping distance of 1.50 in., or a platen acceleration of 0.0087 and an initial clamping distance of 1.20 in.

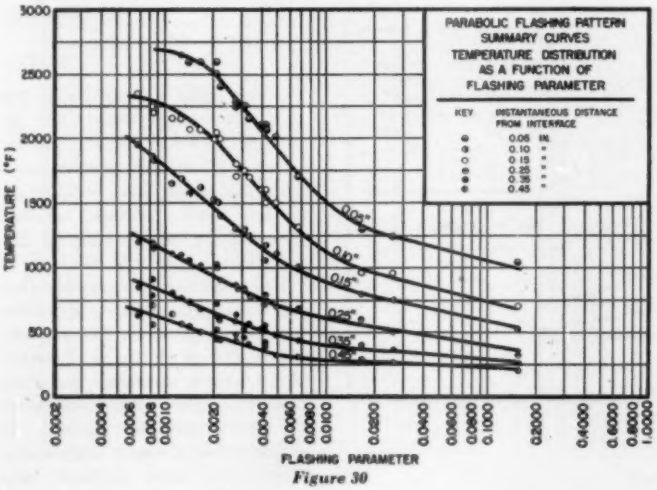

Figure 30

As another example of the use of Fig. 30, suppose an initial clamping distance of 1.30 in. and a platen acceleration of 0.020 in./sec.² are to be used welding 0.30-in. stock, and it is desired to determine how much upset must be employed to remove all material at a temperature above 1650° F. at the instant of upset. In this case, the above information is used to determine the value of the flashing parameter as follows:

$$\text{Flashing parameter} = \frac{\text{Platen acceleration} \times \text{thickness}}{\text{Initial clamping distance}} = \frac{0.020 \times 0.300}{1.30} = 0.0046$$

By interpolation in Fig. 30, it may

Table 3—Summary of Data Used in Plotting Fig. 30

Platen acceleration, in./sec.²	Specimen thickness, in.	Initial clamping distance, in.	Flashing parameter	Stable, stage-two temperatures in ° F. found after 0.20 in./spec. burnoff at distances, in inches from instantaneous flashing interface indicated at top					
				0.05	0.10	0.15	0.25	0.35	0.45
0.004	0.250	1.20	0.000833	...	2200	1830	1150	780	560
0.010	0.250	1.20	0.00208	2500	2050	1500	1000	620	440
0.020	0.250	1.20	0.00416	2100	1600	1180	790	560	390
0.004	0.250	1.50*	0.00067	...	2350	1950	1200	850	630
0.010	0.250	1.50	0.00166	2600	2070	1620	1020	680	500
0.020	0.250	1.50	0.00333	2150	1700	1250	760	570	400
0.040	0.250	1.50	0.00666	1700	1320	1000	670	430	300
0.100	0.250	1.50	0.0166	1300	970	800	600	400	300
0.900	0.250	1.50	0.155	1050	720	530	330	270	210
0.010*	0.250*	1.80*	0.00139*	2600	2050	1550	1050	730	540
0.020	0.250	1.80	0.00277	2250	1750	1300	860	590	430
0.024	0.250	2.78	0.00216	2400	2000	1400	900	600	440
0.054	0.250	2.78	0.00485	2020	1500	1120	700	480	360
0.288	0.250	2.78	0.0259	1250	920	740	500	360	270
0.004	0.375	1.20	0.00125	2650	2150	1680	1100	760	570
0.010	0.375	1.20	0.00312	2250	1750	1300	840	520	460
0.004	0.375	1.80	0.000833	...	2250	1850	1200	920	730
0.010	0.375	1.80	0.00208	2600	2000	1500	1000	730	530
0.020	0.375	1.80	0.00416	2100	1500	1050	720	520	385
0.020**	0.375**	1.80**	0.00416**	2100	1600	1150	750	520	420
0.004	0.500	1.80	0.00111	...	2150	1650	1100	820	640
0.010	0.500	1.80	0.00277	2250	1800	1360	850	630	480

* Performed using abnormally high secondary voltage of 15.7 v.
** Performed with reduced specimen width of 1.10 in.

be seen that, with a flashing parameter of 0.0046, a temperature of 1650° F. is obtained at a point approximately 0.08 in. from the instantaneous flashing interface. Therefore, an upset of at least 0.08 in. per specimen must be employed to remove the over-heated metal.

Effect of Flashing Voltage

Although previous preliminary work[3] had demonstrated that the temperature distribution was not influenced by the flashing voltage, a special investigation was conducted to confirm this observation. Specimens were flashed using an abnormally high secondary voltage of 15.7 v. and the temperature distribution obtained is shown in Fig. 24. Although the flashing action was very coarse and sporadic, the temperature distribution data was found to fit on the summary curves in Fig. 30. This may be seen by inspection of the points plotted for the flashing parameter of 0.00139 used in this portion of the investigation. The agreement is to be expected, since the temperature distribution reflects the over-all rate of heat input during flashing, not the increments in which it is provided. In other words, since the same total amount of heat is required to produce a particular burnoff in a given length of time, the temperature distribution is the same regardless of the character of the flashing. In view of this fact, it is therefore desirable to employ flashing voltages which provide the smoothest flashing action consistent with easy operation. This practice will provide the most uniform flashing interfaces, and the temperature distributions will be unaffected by changes necessary to provide good flashing action with a particular welder.

SUMMARY

This investigation has demonstrated the superiority of parabolic flashing with respect to economy in the burn off required to establish a stable temperature gradient. With linear flashing, it was found necessary to burn off approximately 0.45 in. from each specimen in order to obtain a satisfactorily stable temperature distribution, while the parabolic flashing, 0.20 in. of burnoff per specimen was found to provide a stable temperature distribution in all cases studied. This is attributed to the constant rate of platen acceleration provided by parabolic flashing, which causes the amount of heat created at the flashing interface to increase during flashing at a rate compatible with the increasing rate of heat extraction as the interface nears the jaws. With linear flashing, the heat produced at the interface remains essentially constant, since the rate of burnoff is constant throughout flashing. However, since the flashing interface continuously approaches the water-cooled jaws of the flash welder, the rate of heat flow to the jaws increases as flashing proceeds. This situation requires prolonged flashing to produce a semblance of a stable temperature distribution with linear flashing. On the other hand, with parabolic flashing, the rate of heat production at the interface continuously increases, and thus tends to rapidly stabilize the temperature distribution by matching the rate of heat input to the rate of heat extraction.

The temperature distribution with parabolic flashing was found to depend upon the variables, platen acceleration, initial clamping distance and specimen thickness. A flashing parameter was developed incorporating these variables, permitting comparison of the temperature distributions produced by various

parabolic flashing conditions. By means of temperature distribution curves plotted as a function of the flashing parameter, intelligent selection of flashing variables may be made in terms of desired temperature distributions. This method of selecting flashing variables to produce a desired temperature distribution should prove extremely valuable in future research to be conducted in these laboratories on the upset portion of the flash welding operation, since the conditions at the instant of upset may be accurately predicted from the flashing variables used.

It was demonstrated that decreasing the initial clamping distance, increasing the platen acceleration and increasing the specimen thickness all tended to increase the steepness of the stable temperature gradient produced during parabolic flashing. On the other hand, the temperature distribution was found to be unaffected by the secondary voltage employed during flashing. This latter fact permits selection of a welding voltage consistent with smooth flashing action, without affecting the stable temperature distribution produced.

In most cases, a third-stage temperature distribution was observed in the flashing operation after large amounts of burnoff. During this third stage the temperature gradient became progressively steeper as the flashing interface closely approached the jaws of the welder. Since the distance from the flashing interface of the jaws at the beginning of the third-stage temperature distribution is less than the normal upset distance, no practical significance is attached to the third-stage distribution.

CONCLUSIONS

1. The flashing portion of the flash welding process was investigated using S.A.E. 1020 steel in 0.250- x 2.00-, 0.375- x 2.00-, 0.500- x 2.00- and 0.375- x 1.10-in. specimens.

2. Specimens were subjected only to the flashing portion of the welding cycle, and the temperature distributions obtained were employed as criteria for comparison of various flashing conditions.

3. A stable temperature distribution was found to result after 0.45 in. burnoff per specimen with linear flashing.

4. Parabolic flashing was found to produce a stable temperature distribution after only 0.20 in. burnoff per specimen, allowing a reduction of 0.25 in. per specimen, or 55%, in the burnoff requirements.

5. Increasing the platen velocity with linear flashing was found to produce a steeper temperature gradient.

6. Increasing the platen acceleration rate with parabolic flashing was found to produce a steeper temperature gradient.

7. The secondary voltage employed during flashing was found to have no influence on the stable temperature distribution produced by a given set of flashing conditions.

8. With linear flashing, variations in the initial clamping distance in the range 2.1 to 3.68 in. showed no appreciable effect on the stable temperature distribution.

9. With parabolic flashing, the reduction in the burnoff requirements permitted exploring shorter initial clamping distances, and it was found, in this case, that reducing the initial clamping distance tended to provide a steeper temperature gradient.

10. Increasing the thickness of the specimens was found to produce a steeper temperature gradient.

11. Changing the width of the specimens was shown not to influence the stable temperature distribution.

12. An empirical flashing parameter was developed, defined by the equation,

$$\text{Flashing Parameter} = \frac{\text{platen acceleration (in./sec.}^2\text{)} \times \text{thickness (in.)}}{\text{initial clamping distance}}$$

which permitted comparison of various flashing conditions in terms of the stable temperature distributions produced.

13. A family of curves were produced showing the stable temperature at each of six positions relative to the flashing interface as a function of the flashing parameter.

14. Examples of the use of this family of curves in the selection of flashing conditions were given.

ACKNOWLEDGMENTS

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Appendix I

The 300-kva. flash welder at the Rensselaer Polytechnic Institute Welding Laboratories was modified to provide more flexible operation by designing a new sequence control mechanism. Originally the sequence control was provided by a motor driven cam shaft, operated at constant speed. A cam mounted on this

shaft operated a hydraulic servomechanism which controlled the motion of the movable platen in accordance with the contour of the cam. Thus, the platen displacement as a function of time was determined by the cam rise per degree of angular rotation and the angular velocity of the cam shaft. Adjustment of the angular velocity of the cam shaft was provided by means of a Reeves-drive mechanism and a set of interchangeable gears. This system was difficult to calibrate sufficiently well to permit easy duplication of flashing conditions, and changes in the type of flashing pattern could be obtained only by changes in the cam contour.

Experience had shown that the following features would be desirable in a sequence control for the movable platen in flash welding.

1. A slow constant velocity of approach to permit easy starting of the flashing operation without special end preparation.

This approach velocity should be independent of the subsequent flashing pattern, and should be adjustable to provide for selection of a suitable velocity of closure.

2. A means of altering the type of flashing pattern, without substitution of special cams.

3. A means of easily varying the platen time-displacement pattern which would permit consistent duplication of welding conditions, and greater flexibility.

As a result of careful study, it was decided that an all electronic system of controlling the cam shaft velocity would be desirable, so the following system was designed and constructed.

A $^3/_4$ hp. shunt wound d. c. motor was substituted for the original $^1/_2$ hp. 3 phase a. c. motor used to drive the cam shaft, and power for the d. c. motor was obtained from an all electronic speed control panel. In this way, two thyratron tubes were employed to provide the rectified direct current for operation of the motor, and automatic regulation of the motor speed was provided. In this type of speed control, a voltage signal proportional to the motor speed is obtained from a tachometer, and is used in conjunction with a reference voltage to control the firing pattern of the thyratrons. Thus, any change in the speed of the motor from the desired speed produces a similar change in the output voltage of the tachometer, which in turn adjusts the conduction period of the thyratrons to restore the motor speed to the desired value. Such controls are readily available commercially, and a commercial model was adapted for this problem, the major change being in the type of reference voltage employed to regulate the motor speed.

From the equations in the footnote on page 588-s, it may be seen that a linear flashing pattern is one of constant velocity, while a parabolic flashing pattern is one of constant acceleration. Therefore, in order to obtain a linear flashing pattern, the reference voltage is maintained at a constant value thus keeping the motor speed, and therefore the cam shaft velocity constant within $\pm 1\%$. The platen motion is then produced by a cam which has a linear rise with angular rotation. Various linear velocities may be obtained by merely changing the value of the reference voltage by means of a calibrated dial on a limiting potentiometer.

A parabolic flashing pattern may be generated using the same cam by causing the reference voltage to rise at a constant rate. This produces a constant rate of acceleration, which, in turn, produces a linear increase in the angular velocity of the cam shaft with time, and thus a constant acceleration of the movable platen. The reference voltage was obtained from a bank of capacitors, charged by an adjustable, constant-current source. Thus by changing the charging rate of the capacitors, the rate of change in the reference voltage with time could be readily varied. A calibrated potentiometer, mounted on the control panel, allowed selection of charging rates corresponding to a wide range of platen accelerations. Any platen acceleration from 0.004 in./sec.^{2} to 0.10 in./sec.^{2} could be obtained in this way without changing the motor to cam shaft gear ratio.

By blocking the voltage on the capacitors at a low value during the initial closure period, a slow, constant velocity of approach was provided. A relay, actuated by the first pulse of flashing current, started charging of the capacitors providing the reference voltage, and thus initiated the acceleration period. If a linear flashing pattern was desired, the acceleration rate was merely set at the maximum and the charging of the capacitors halted at the appropriate reference level to maintain to desired speed.

This system has been used over a period of nearly six months, and it has been found possible to duplicate flashing rates within 2% from the calibrated control dials throughout this period. No maintenance work has been necessary, although the equipment has been in service several hours a day throughout this period, and the original calibrations are still valid.

A detailed report including the design data on this sequence control will be written and published at some future date.

Improvement of Inert-Gas Welding by Using High-Purity Helium

Some metals such as aluminum require the use of high-purity helium, if sound, nonporous welds are to be obtained

by William A. Mays

Abstract

The helium-shielded arc-welding process produces sound, nonporous welds on aluminum, magnesium, stainless steel, and many other hard-to-weld metals. High-purity helium is desirable for shielded-arc welding; for welding some metals, particularly aluminum, it is necessary to use the high-purity gas. If the helium is contaminated with even minute quantities of other gases, such as oxygen, nitrogen, hydrogen, water vapor or oil vapor, inferior aluminum welds are obtained. Helium of 99.99 + % purity, termed Grade-A has been found quite satisfactory for use in inert-gas welding. The present paper describes and discusses the effects of various impurities on the welding of aluminum, and describes the precautions necessary in handling high-purity helium to avoid contamination.

INTRODUCTION

THE use of helium as a protective atmosphere for arc welding was patented in 1930 by H. M. Hobart of the General Electric Co. However, it was not until the early part of World War II that the process was used on a commercial scale. At that time, rapid expansion of the aircraft industry increased the demand for metals such as magnesium, aluminum and stainless steel. A method for welding highly flammable magnesium was needed, and the inert-gas-shielded arc-welding process was tested. Equipment used consisted of an electrode holder designed to fit an essentially nonconsumable tungsten electrode. A ceramic or metallic nozzle, mounted concentric with the tungsten electrode and attached to the holder, made an annulus through which a flow of helium was passed. The helium flowing from the annulus about the electrode shielded the weld area with a blanket of inert gas and thus prevented contact of air with the molten metal. Magnesium and magnesium alloys were successfully welded, using this technique, and the process was accepted by the aircraft industry for production work.

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The only helium available in commercial quantities for this initial work had a purity of 98.2%.[1] This grade of helium was supplied by the Bureau of Mines to Government agencies and to industry until February 1948. Since that date, much purer helium has been supplied, particularly for use in welding.

The successful welding of magnesium created widespread interest in the inert-gas-shielded arc-welding process, and it was tested for welding other metals. The process was found to be excellent for welding stainless steels, especially thin-gage sheet. However, when the process was tried for welding aluminum, numerous difficulties were encountered. It was found that the welding circuits used for magnesium and stainless steel were not satisfactory for welding aluminum. Independent research programs were started by several welding-equipment manufacturers to develop a welding power supply suitable for welding aluminum. Welding circuits using a. c. were tried, and some improvement was obtained. Special a.c. welding transformers were developed for this work, and the welding of aluminum alloys was attempted, using the a.c. circuits and 98.2% helium; however, the welds obtained were not entirely satisfactory. The Bureau of Mines had participated in some of this work through cooperative programs, and it was thought that higher-purity helium would improve results. Recognizing the importance of the application of helium in shielded-arc welding, the Bureau started a research program in 1946, to study the effects of impurities in helium and to determine whether a higher-purity helium was needed for welding.

Analysis of the 98.2% helium had shown that it contained approximately 1.7% nitrogen and 0.1% hydrogen. One phase of this investigation was to determine the effects of these impurities on helium-shielded arc welding. Cylinders used for shipping inert gases, manifolds, fittings and gas-supply lines used for transferring inert gases frequently are exposed to air, water vapor, or oil. If these constituents are not removed by proper cleaning, evacuation and purging, the helium will be contaminated, and, therefore, it seemed advisable to investigate the effects of these impurities also.

NEED FOR HIGH-PURITY HELIUM

To study the effects of impurities in helium used for inert-gas welding, it was decided that the best method for preparing gas samples of known composition was to introduce known amounts of impurities into a cylinder containing high-purity helium. This necessitated a supply of high-purity helium. In 1947, when this phase of the investigation was initiated, small quantities of high-purity helium had been prepared on a laboratory scale by passing 98.2% helium over activated charcoal at low temperatures (−250 to −300° F.). It was known that activated charcoal at low temperatures would adsorb nitrogen and hydrogen, the principal impurities in helium. Purification of the 98.2% helium by this method produced a product having a purity of 99.5% or higher. This grade of helium was tested for welding, and the results indicated that gas of even higher purity than this would be desirable for certain welding applications. Therefore, the Bureau of Mines designed and installed purification equipment for producing helium of a higher purity. Adapting this new equipment to the production process required several changes; but these were made as conditions warranted, and eventually helium was produced that analyzed 99.99+%. This product, termed Grade-A helium, proved very satisfactory for inert-gas welding, and in February 1948 routine production of helium of this purity was started. In as much as some of the earlier experiments on welding had been made with helium of 99.5% purity, it was decided to repeat the tests, using helium of essentially 100% purity to obtain additional and more accurate data.

Previous work had shown that the effects of impurities in helium were very pronounced on aluminum welds; and, therefore, coupons of aluminum were used for the experimental studies in this investigation. Commercially pure aluminum, alloy 2S, was used to eliminate any possible effects that might be produced by alloying constituents.

PREPARATION OF CONTAMINATED HELIUM MIXTURES

To prepare contaminated helium mixtures, known quantities of nitrogen, hydrogen, air, oil and water were introduced into dried and evacuated helium cylinders. Each cylinder was then filled to a specific pressure with high-purity helium. Special attention was given to make sure that the cylinders were dry and free of any possible contamination. After the mixtures had been prepared, the cylinders were spot-heated to produce convection currents and effect as complete a mixing of the components as possible. The samples were then analyzed for impurities. The hydrogen- and air-contaminated mixtures were analyzed just before the weld tests were made. Water-contaminated mixtures were analyzed for water vapor during the time weld tests were being made. This was done by connecting a dew-point recorder into the line supplying gas for the welding experiments.

Oil-contaminated helium mixtures were prepared by removing the valve from a clean, dry cylinder and introducing 30 cc. of compressor oil into the cylinder. The oil was distributed on the internal surface of the cylinder walls by swabbing and by rotating the cylinder. The valve was then replaced in the cylinder and the cylinder was evacuated, purged, and filled with high-purity helium. After filling, the cylinder was heated to approximately 150° F. and then allowed to cool before weld experiments were made.

WELDING EQUIPMENT AND TESTING PROCEDURE

Equipment used for making the weld tests consisted of a 400-amp., a.c., inert-arc welding generator and a water-cooled, tungsten electrode holder mounted on a variable-speed carriage mechanism. Figure 1 shows the welding equipment. Aluminum coupons measuring 1 by 6 in. were sheared from 12-gage sheet, and the edges of the coupons were filed to make good joint alignment. Clean samples were clamped on a 90-degree corner jig and welded without using filler metal. All test welds were made using a current setting of 95 amp. and a gas flow of 26 cu. ft. per hour. A $^{5}/_{32}$-in. diameter tungsten electrode was used in an inert-arc electrode holder, which was clamped on a variable-speed carriage mechanism. This mechanism was set to move the holder at a welding speed of 26 in. per minute.

In making weld tests with the contaminated helium, a cylinder was connected to the helium supply line on the electrode holder, and the lines were purged for 5 min. before weld tests were made. After purging was complete, weld samples were made on each contaminated helium mixture. Helium supply lines were purged thoroughly with high-purity helium after each test.

EFFECTS OF HYDROGEN

To investigate the effects of hydrogen contamination, weld samples were made using helium contaminated with 0.01, 0.02, 0.025, 0.03, and 0.04% hydrogen. Welds were then examined visually and microscopically and compared with welds made using high-purity he

Fig. 1 Equipment used for weld tests

lium. It was found that hydrogen produced porosity in the welds, and the porosity increased as the hydrogen content increased. This was visually evident on the surface of welds. Although the amount of porosity evident on surfaces of welds made with 0.01% hydrogen was minute, it could be observed. Figure 2 is a photomacrograph of a weld made with helium containing 0.3% hydrogen. Several welds were made with helium containing greater percentages of hydrogen than reported in this investigation. The weld made with helium containing 0.3% hydrogen was photographed because it was a good example of surface porosity and internal porosity. Figures 3 and 4 are photographs of a weld made with high-purity helium. The smooth-surface appearance and the absence of porosity are notable.

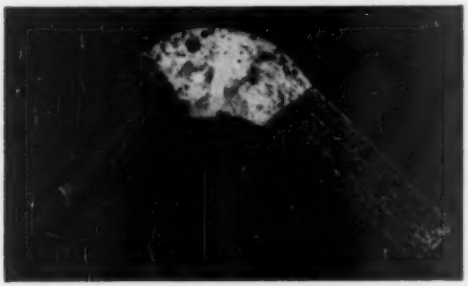

Fig. 2 Internal porosity on sample welded with helium containing 0.3% hydrogen, 6 ×

EFFECTS OF NITROGEN

Previous work on the effect of nitrogen in helium had shown that nitrogen produced a brown discoloration on the weld surface; also, it made it difficult to obtain good fusion on the aluminum coupons. Samples welded with helium containing as much as 1.5% nitrogen were, in many respects, similar to welds made with 98.2% helium. It has been shown[2] that aluminum and nitrogen react at high temperatures to form aluminum nitrides. From examination of the surface appearance of the welds made, it was evident that nitrogen was detrimental to the welding of aluminum.

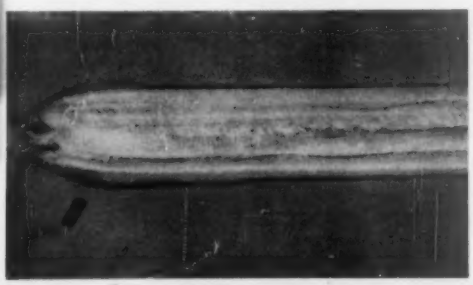

Fig. 3 Surface appearance of weld made with high-purity helium, 2 ×

Fig. 4 Section of weld made with high-purity helium, 6 ×

No tests were made using minute percentages of nitrogen, as it was believed that any nitrogen present in the original gas would be removed by the newer purification process. If nitrogen were detected in the helium, it would doubtless result from air contamination of the helium after it had left the purification unit.

EFFECTS OF AIR

Four air-contaminated helium samples having 0.01, 0.02, 0.05, and 0.71% air were used for weld tests. The aluminum welds made with the 0.01 and 0.02% air mixture had brown scale at the edges of the weld. This scale, probably oxides and nitrides, could be seen floating in the pool of molten weld metal at the time the welds were being made. As the arc progressed along the seam, the scale was forced to the edges of the weld

Fig. 5 Surface appearance of weld made with helium containing 0.71% air, 2 ×

crater and solidified on the sides of the weld bead. In making these welds, the arc was very unstable and had a fluttering action. When the 0.71% air mixture was tried for welding, the arc could not be maintained for the time required to traverse a 6-in. length of weld seam. Instead, the arc was extinguished frequently, and the parts of the seam subjected to the arc were highly oxidized and had a rough surface. Metallographic sections of the weld showed poor fusion and under-bead cracking. Figure 5 shows the surface appearance of the weld made with 0.71% air. The scale produced by air-contaminated helium samples prevented good fusion of the metal, and in multipass

welding this scale would have to be chipped out after each successive pass if sound welds were to be made.

EFFECTS OF WATER VAPOR

Welds were made with each of the water-contaminated helium samples, and the welds were compared with those made using high-purity helium. The water-contaminated helium mixtures produced scale on the edges of the weld bead very similar to that obtained with air-contaminated helium mixtures. In addition, porosity could be observed on the surface of the welds. This condition might be expected, inasmuch as water vapor at the temperature of the arc would be dissociated into hydrogen and oxygen. Porosity could be observed on the aluminum welds made with a helium-water vapor mixture containing 0.004 mol-per cent water (a water dew point of +33° F. at 2100 psi.). Increased amounts of water vapor produced greater amounts of porosity and scale on the welds. Control samples welded with high-purity helium containing only 0.0005 mol-percent water (dew point of −16° F. at 2100 psi.) were free of scale and porosity. After weld tests were made with a water-contaminated mixture, all helium supply lines were purged with high-purity helium before another mixture was used. Lines were purged until a satisfactory weld could be made, and it was found that prolonged purging was necessary to remove water-vapor contamination from the lines. These tests have shown that it is necessary to keep all manifolds and helium supply lines dry to produce sound welds.

EFFECTS OF OIL VAPOR

In studying the effects of oil contamination in helium used for inert-gas welding, several preliminary experiments were made. A heavy compressor oil having a viscosity of 145–155 S.U.S. at 210° F. was used for these experiments because it was thought that, if a heavy oil contaminated inert gases, any lighter, more volatile oil would also produce adverse effects. As an experiment, the metal fitting in the electrode holder was coated with a thin film of the heavy compressor oil. This fitting was exposed to the inert-gas stream and a supply of high-purity helium was passed through the electrode holder and used for making weld tests. A photograph of the first weld obtained is shown in Fig. 6. As can be seen from the photograph, a very poor weld was produced, and the surface was very rough and scaly. The aluminum coupons were not completely fused, and a scum was evident on the surface of the metal where it had been subjected to the arc. Several welds were made in succession, and, with each successive weld, the amount of scum in the weld decreased. The fitting in the electrode holder was removed after this series of welds had been made, and a film of oil was still evident on the surface of the fitting. The remaining oil was removed by washing the fitting in carbon tetrachloride, and then no difficulty was experienced in making good, sound welds with high-purity helium.

Fig. 6 Surface appearance of weld made with oil-contaminated helium, 2 ×

These tests showed that high-purity helium at relatively low pressures may be easily contaminated by oil present in the lines or fittings. These tests did not show, however, whether helium at high pressures would be contaminated by oil present in helium cylinders. Therefore, oil was introduced into a helium cylinder, the cylinder evacuated, and then filled to a pressure of 1200 lb. per square inch with high-purity helium. Mixing was done in the manner described previously. The first weld made using helium from the cylinder containing oil was very similar to that obtained in the experiments described above. The succeeding welds had less scum and scale; however, after a series of five welds had been made, the helium supply line was purged several minutes with the oil-contaminated helium and another weld was then made. This weld was similar to the first and had a very rough, scaly surface. Purging the electrode holder for several minutes with oil-contaminated helium apparently left an appreciable amount of oil in the nozzle and the electrode holder. No tests were made to determine how much oil was present in the gas used for welding, nor was a limit determined on the amount of oil that could be detected by means of the weld test. It did not seem important to investigate these factors inasmuch as the helium-production process will remove any oil present in the helium, and efficient means are available for removing oil from shipping containers. The tests made showed very definitely that oil present in gas-supply lines, fittings, or cylinders can contaminate helium and produce very adverse effects on welding.

CLEANING AND PURGING OF SHIPPING CONTAINERS

The investigation reported herein has shown the importance of using high-purity helium for inert-gas welding. Helium of 99.99+% purity (Grade-A) is now produced by the Bureau of Mines for this purpose; however, proper precautions must be taken to maintain this purity. To produce high-purity helium and then charge it into cylinders or tank cars that contain air, water, oil, or other contaminants would nullify the entire effort put forth in making a high-purity product. For this reason, special consideration is given to internal cleanliness of shipping containers in which Grade-A helium is shipped. An effective program has been es-

tablished for internal cleansing of cylinders and tank cars used for high-purity helium. Under this program, valves are removed from Bureau of Mines cylinders used for Grade-A helium shipments, and they are washed internally with a hot-water solution containing detergents. Oil and contaminants are removed by the wash solution, and then the cylinders are rinsed with hot water. Water is drained from the containers, and they are dried, using hot air. Valves are replaced in the cleaned cylinders. The cylinders are then evacuated to an absolute pressure of a few millimeters of mercury, charged with high-purity helium, re-evacuated, then filled with high-purity helium to a pressure of 2400 lb. This program of washing, drying, and filling containers used for Grade-A helium shipments has proved satisfactory and ensures against contamination.

PRECAUTIONS IN HANDLING GRADE-A HELIUM

In any operation involving rehandling or transfer of helium, it is necessary, of course, to take adequate precautions to avoid contamination of the helium. Occasionally it may be necessary to cascade helium from tank cars into conventional compressed-gas cylinders, or it may be necessary to cascade helium from one group of cylinders to another. In any of these operations, steps must be taken to insure that the cylinders used are free of air, oil, water, and other contaminants and that all valves, fittings, and lines are free of contamination. The responsibility for maintaining the original high purity of the gas in these operations must necessarily be assumed by distributors and consumers.

The tubing used for helium-supply lines on inert-gas welding equipment should be either a good grade of rubber or plastic. Experiments on several types of tubing have shown that worn or dried-out rubber tubing is undesirable, as air or water vapor may diffuse into the tubing and contaminate the helium. A good grade of tubing will insure against contamination as well as minimize the loss of helium from leakage.

CONCLUSIONS

For welding aluminum and some of the other metals, high-purity helium must be used if sound, nonporous welds, free of oxides and inclusions, are to be obtained. Bureau of Mines Grade-A helium is essentially 100% pure, and this product has been widely accepted by industry for inert-gas welding because of the vast improvement obtained in welding many of the hard-to-weld metals. Every precaution must be taken by the distributor and customer to maintain this purity if the best results are to be obtained.

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WELDING RESEARCH COUNCIL BULLETINS

The Welding Research Council has inaugurated a series of Bulletins to include reports for which space cannot be provided in the regular Welding Research Supplement. These Bulletins are furnished to the contributors and research workers of the Council and placed on sale at a nominal charge through the AMERICAN WELDING SOCIETY. A list of the Bulletins published to date and their prices are:

No. 1. *Steel Compositions and Specifications*, by Charles M. Parker, March 1949. Price: Fifty cents.

No. 2. *The Nature of the Arc*, by J. D. Cobine, April 1949. Price: Fifty cents.

No. 3. *Burn-Off Characteristics of Steel Welding Electrodes*, by D. C. Martin, P. J. Rieppel and C. B. Voldrich, May 1949. Price: Fifty cents.

No. 4. *Testing Pressure Vessels*, by F. G. Tatnall, and *Effect of Welding on Pressure Vessel Steels*, by A. F. Scotchbrook, L. Eriv, R. D. Stout and B. G. Johnston, February 1950. Price: Fifty cents.

No. 5. *How Plastic Deformation Influences Design and Forming of Metal Parts*, by John R. Low, Jr., and *Brittle Fracture in Mild Steel*, by J. S. Hoggart, May 1950. Price: One dollar.

No. 6. *Stress Corrosion Cracking of Stainless Steels*, by Helmer Nathorst. Part I—Practical Experiences; Part II—An Investigation of the Suitability of the U-bend Specimen, October 1950. Price: One dollar.

No. 7. *Instrumentation for the Evaluation of the Stability of the Welding Arc*, by L. P. Winsor, L. McDonald Schetky and R. A. Wyant, November 1950. Price: One dollar.

No. 8. *Tests of Columns Under Combined Thrust and Moment*, by L. S. Beedle, J. A. Ready and B. G. Johnston, December 1950. Price: One dollar.

No. 9. *Copper in Stainless Steels*, by Helmut Thielsch, August 1951. Price: One dollar.

Relation of Notch Strain to Deflection in the Notch-Bend Test

An experimental investigation of the strains developed at the base of the notch in a longitudinal notch-bend specimen used for the evaluation of weld ductility

by E. M. Emery and A. E. Flanigan

1. INTRODUCTION

IN RECENT years there has been an increasing use of the longitudinal notch-bend test in studies concerned with the ductility of welds. Several versions of the test have been employed,[1–4] the specimens varying with respect to over-all dimensions, welding conditions, weld length, notch contour and notch depth. In the various versions, the specimen is bent until some suitable criterion of failure is reached, and the corresponding values of bend angle or deflection (defined in Fig. 1) are then reported as the measure of ductility.*

In the case of mild steel welds, the fracture of the specimen is generally found to originate in the weld metal itself. Thus the values of bend angle and deflection which attend the appearance of such a fracture serve as a measure of the weld's capacity for deformation. To one interested in the properties of the weld itself (rather than those of the composite plate), it would perhaps be preferable to know the actual strain occurring at the base of the notch. Direct measurement of this "notch strain" is, of course, difficult since the dimensions involved are small. Furthermore, there would seem to be no satisfactory method of calculating notch strain from corresponding values of the measurable quantities.

This paper describes an attempt to determine experimentally the relation between notch strain and deflection** in a version of the test which has been used extensively at the University of California at Los Angeles. The desired relation was found to be nearly linear over the range investigated. Furthermore, the relation appears to depend not only on the specimen's geometry but also upon its metallurgical condition. The importance of the latter factor, one of considerable interest, will be discussed in a later section.

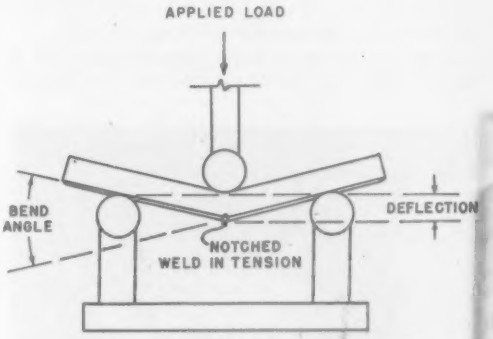

Fig. 1 The longitudinal notch-bend test

Only the longitudinal strains (those parallel to the axis of the weld) were measured. Since the bending of the proportionately wide and shallow specimen is undoubtedly attended by a condition of biaxial stress at the base of the notch, it is recognized that it would have been of interest to determine the transverse strains as well. The latter measurements, however, were not attempted.

2. SPECIMEN PREPARATION, BENDING AND STRAIN MEASUREMENTS

Figure 2 shows the appearance of a typical specimen after bending. The 4- by 9-in. blanks were flame-cut from $^3/_4$-in. A.S.T.M. A285-C plate containing 0.17% C, 0.38% Mn, 0.04% Si, 0.031% Su, and 0.013% P. The full-length weld was deposited with a popular

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Paper presented at the Thirty-Second Annual Meeting, A.W.S., Detroit, Mich., week of Oct. 15, 1951.

* The term "ductility" will be used loosely throughout this paper to denote capacity for plastic deformation.

** Few further references will be made to the term "bend angle." It is to be understood, however, that the deflection readings which are reported in this paper could, if desired, be converted readily to bend-angle values since there exists an easily established, and essentially linear, empirical relation between these two quantities.

Fig. 2 The longitudinal notch-bend test specimen

brand of A.W.S. E6010 electrodes at 170 amp., 26 v. and an arc speed of 8 in. per minute. Following welding, each specimen was placed on a wooden surface to cool to room temperature in still air. Later, a transverse U-shaped notch of $^1/_{16}$ in. radius was milled across the specimen to a depth of 0.020 ± 0.003 in. measured from the plate surface at the edge of the weld. The base of the notch was then polished with 4/0 emery paper.

Under the welding conditions employed, the width of the weld bead and the height of the crown were approximately $^1/_2$ and $^3/_{32}$ in. respectively, while the penetration of the weld into the plate was approximately 0.10 in. Figure 3 shows the relation between the contour of the notch and the depth of penetration along the center line of the weld. It is apparent that the base of the notch was located well within the weld in this region.

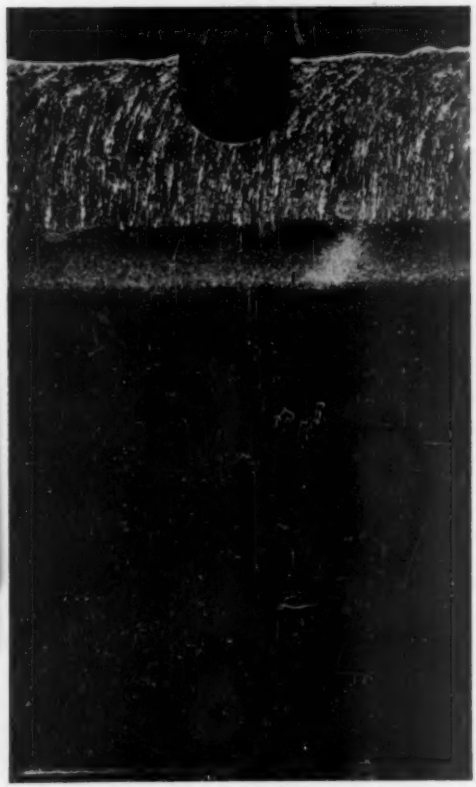

Fig. 3 Notch contour, center-line section through full thickness of welded specimen

Gage marks were prepared at the base of the notch by painting the surface with a thin coat of machinists' layout blue after which sharp parallel scratches were scribed through the bluing into the steel. The average scratch width was approximately 0.0013 in. Appendix 1 describes an experimental justification of the use of such scratches. A gage length of approximately 0.020 in. was used in all of the tests. Supplementary studies indicated that such a length was sufficiently short to characterize the local strain at the base of the notch. After bending, the strains were measured optically with a toolmakers' microscope at 75 × (Fig. 4).

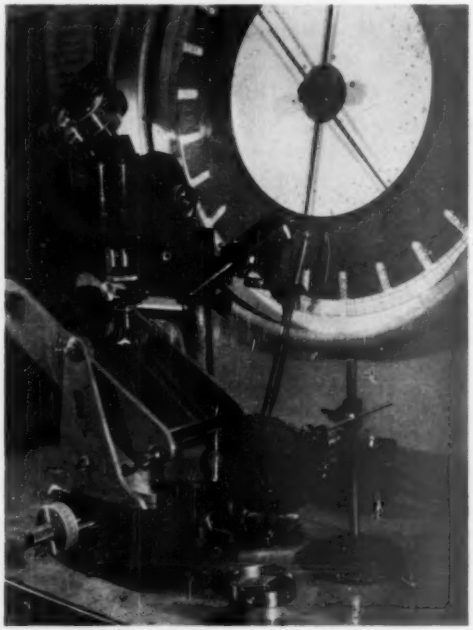

Fig. 4 Strain measurement apparatus

The bend tests were conducted five days after welding. The bending fixture, indicated schematically in Fig. 1, incorporated a span length of 6 in. The radii of the supporting shoulders and of the loading plunger were in each case $^5/_8$ in. The specimen was centrally loaded as a simply supported beam with the welded side in tension.

3. THE STRAIN-DEFLECTION RELATIONSHIP FOR AS-WELDED SPECIMENS

The work described in this section was designed to

reveal for the as-welded condition the relation between the longitudinal strain at the base of the notch* and the deflection of the specimen in the bend test. Seven specimens were prepared and tested. The bending of each specimen was interrupted, generally at 0.100-in. intervals of deflection, to permit the evaluation of strain. Such a procedure, of course, may cause one to wonder if the same relation would have been obtained had no interruptions occurred during bending. On the basis of auxiliary tests (Appendix 2), it is believed that equivalent results would indeed have been achieved.

Figure 5 shows the results obtained in the tests. It will be noted that the relation between notch strain and deflection† appears to be essentially linear. Such an indication is of interest since it enhances the direct significance of the deflection and bend angle values which are commonly reported in the notch-bend test.

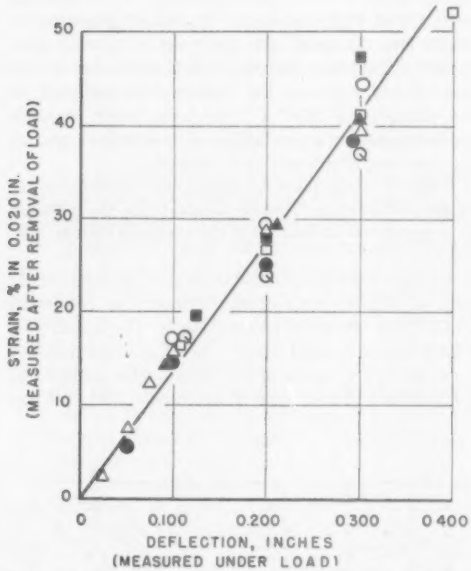

Fig. 5 Relation of notch strain to deflection for the as-welded condition
(The 7 symbols refer to 7 individual specimens.)

This point may be illustrated, for example, by reference to a study of the strain aging of welds conducted recently in this laboratory.[5] It was found that aging at room temperature following straining induced a considerable reduction in the specimen's residual capacity for deformation. Values of bend angle were used to measure ductility (see the second footnote in Section 1) and it was conceivable that the use of such a method might tend to yield exaggerated indications of the actual strain-aging capacity of the weld. In view of the linear relation in Fig. 5, it would now appear that a given loss (say 60%) in bend-angle ductility corresponds to an equally severe loss (also 60%) in the actual straining capacity of the weld.

In the case of Fig. 5 and similar figures which follow, the greatest value of strain shown for each specimen corresponds to that interruption of bending for which a crack was first observed in the notch at a magnification of 75×. (The first cracks were found to occur in the weld metal rather than in the heat-affected zone.) After cracking had first been observed each test was discontinued. In six of the seven specimens, cracks were first noted at a deflection of 0.300 in. (i.e., they presumably occurred in the range from 0.200 to 0.300 in.). In the other instance, cracks were first observed at a deflection of 0.400 in. and hence are presumed to have been initiated in the range from 0.300 to 0.400 in. In all cases the cracks were so small that the first subsequent strain measurements are believed to have been little affected.

4. THE INFLUENCE OF THE WELD CROWN

In section 3 it was noted that the initial fracture of the specimens occurred in the weld metal itself rather than in the heat-affected zone or in the plate. The presence of the "weld crown" (that portion of the weld bead above the surface of the plate) of course served to accentuate the depth of the notch at the weld. As a consequence, it is not clear whether one should attribute the occurrence of initial cracking in the weld to the inferior notch resistance of that region or to the fact that it was subjected to a deeper, and hence more severe, notch than were the other locations.

For clarification of this matter, and to determine quantitatively the influence of the weld crown on the strain-deflection relation, three specimens were tested after their welds had been ground flush with the surface of the plate. They were otherwise similar to the specimens of Section 3. Again the notch was cut to a depth of 0.020 in. below the plate surface.

Curve B of Fig. 6 shows the relation of notch strain to deflection for these specimens. For comparison it also includes the "crown-on" curve from Fig. 5 (curve A). It may be noted that the new relation is again approximately linear and that the strain concentration at the base of the notch has been decreased by about 30% by removal of the crown.

It was observed in these tests that, even in the absence of the crown, the fracture of the specimen originated in the weld metal.

5. THE METALLURGICAL FACTOR

One might expect that the strain-deflection relation for a longitudinal specimen of given geometry would depend upon the geometry of the specimen alone, and that it would be unaffected by the presence of a weld so long as the latter did not alter the geometry. Ac-

* Auxiliary tests, related in Appendix 3, indicated that a greater value of strain occurred at the base of the notch than at other locations.
† All deflections related in this paper were measured under load while the strains were measured after unloading.

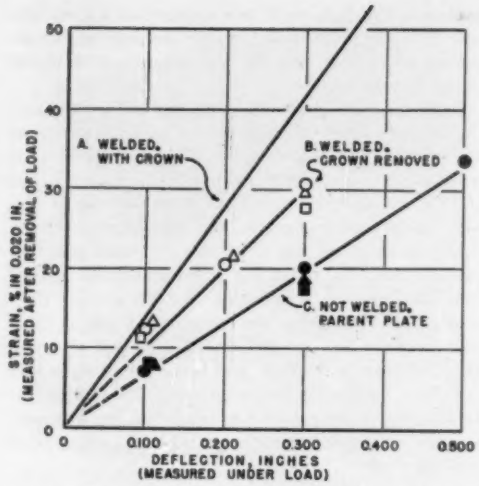

Fig. 6 Influence of the weld crown on strain-deflection relation
(The 6 symbols refer to 6 individual specimens.)

cordingly, it might be expected that the crownless but weld-bearing specimen of Section 4 would behave in the same manner as a geometrically identical but weldless specimen consisting of plate alone.

To test such a possibility, three such specimens were prepared and were tested in the usual manner. The resulting strain-deflection relation is shown as curve C in Fig. 6. It may be seen that the relation, again linear, is considerably different than that obtained with the geometrically identical specimens containing ground-off welds (Curve B). The strain concentration has been reduced by approximately 40%.

It would appear that the relation for the crown-bearing specimen is dependent not only on the presence of the crown, a geometrical influence, but also on the presence of the weld, a metallurgical factor. The geometrical effect is seen by comparing curves A and B in Fig. 6, while the metallurgical effect is represented by comparison of curves B and C.

Perhaps, as has been suggested by other writers in recent years, it is desirable to think in terms of "metallurgical notches" as well as geometrical notches in the case of structures bearing welds. Figure 6 would seem to support such a belief. The changes in section which constitute a geometrical notch are perhaps paralleled by the severe gradients of metallurgical structure which are characteristic of welds.

6. POSTHEATED WELDS

The foregoing indications concerning the role of a metallurgical factor suggest that, in the case of welded specimens, the application of thermal treatments might be expected to influence the strain-deflection relation. This section deals with tests designed to illuminate such a possibility.

Following welding, six specimens were postheated at various temperatures for a period of one hour, after which they were cooled in air. Later they were notched and tested in the usual manner (without removal of the weld crown). Three of the specimens were treated at 1280° F., two at 1500° F. and one at 1600° F.

The resultant strain-deflection data are shown in Fig. 7 together with the curve for the nonpostheated condition taken from Fig. 5. It is recognized that the use of such a small number of specimens casts doubt on the precise validity of the curves which have been drawn to fit the data of Fig. 7, but it is believed, nevertheless, that significant trends are apparent. It would appear that, for the range of temperature employed, an increase in postheating temperature produces a decrease in the ratio of notch-strain to deflection. If one postulates the importance of a metallurgical factor, such an indication is of course not surprising. It is to be expected that high-temperature postheating treatments would tend to level out the original metallurgical gradients and hence that they would cause the welds to more nearly approach the homogeneous condition of the plate. The 1600° F. treatment, which probably induces complete recrystallization, would be expected to most nearly achieve this condition.

Figure 7, then, must be regarded as supporting the earlier indications of Section 5 concerning the influence of a metallurgical factor on the strain-deflection relation.

Another interesting observation may be based on the data of Fig. 7. One of the authors has previously studied the effects of postheating on the ductility of E6010 welds in mild steel.[3] In that work ductility was reported in terms of the bend angles achieved at fracture in a similar type of notch-bend test. It was

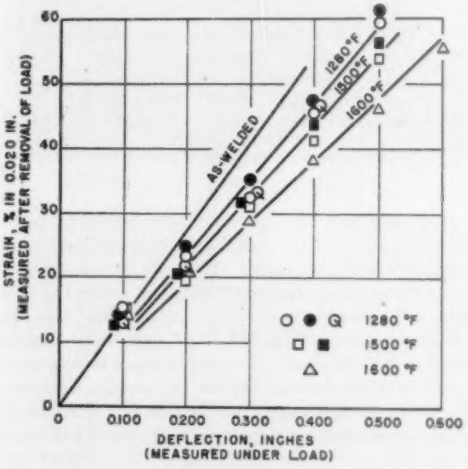

Fig. 7 Influence of postheating on the strain-deflection relation

found that considerable improvement in bend angle was produced by postheating. In the light of Fig. 7, it would now appear that the use of the bend-angle criterion probably led to somewhat greater indications of benefit than would have accrued had weld-metal strain been measured directly.

7. CONCERNING OTHER TYPES OF SPECIMENS

It is emphasized that the results related in this paper are based upon the use of a particular geometry and particular materials in the test specimen. Obviously, certain of the results cannot be expected to apply directly to other types of tests in common use. This is certainly true of the particular values which have been derived for the strain-deflection ratios under various conditions. It seems not unreasonable, however, to suppose that the approximate linearity of the strain-deflection ratios may be generally applicable, at least over limited ranges of strain. Similarly, one might expect the importance of the metallurgical factor to affect other types of tests.

8. SUMMARY AND CONCLUSIONS

1. A method has been developed for measuring the strains at the base of the notch in longitudinal notch-bend specimens used to evaluate weld ductility.

2. Through the use of this method, the relations between notch strain and specimen deflection have been determined for a particular type of specimen tested under various conditions. The specimen was that which has been used previously at the University of California in welding studies.

3. For the conditions investigated, the strain-deflection relation was found to be approximately linear over the range of strains preceding and immediately following the fracture of the weld.

4. The strain-deflection ratio was found to be dependent upon the metallurgical condition of the weld as well as upon the geometry of the specimen. This dependency is believed to indicate the existence of what may be termed a "metallurgical notch." It is suggested that important implications stem from this evidence.

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2. Flanigan, A. E., "An Investigation of the Influence of Hydrogen on the Ductility of Arc Welds in Mild Steel," *Ibid.*, 26 (4), Research Suppl., 193-s to 214-s (1947).
3. Stout, R. D., McGeady, L. J., Sun, C. P., Libsch, J. F., and Doan, G. E., "Effect of Welding on the Notch Sensitivity and Ductility of Some Ship Steels," *Ibid.*, 26 (6), Research Suppl., 335-s to 357-s (1947).
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5. Flanigan, A. E., Kaufman, M., and Emery, E. M., "Strain-Aging of Arc Welds in Mild Steel," THE WELDING JOURNAL, 29 (3), Research Suppl., 146-s to 160-s (1950).

Appendix 1. The Effect of Scratched Gage Marks

It is conceivable that the use of sharp scratches for gage marks might cause the strain indications to be greater than if scratchless marks were to be employed. For this reason, an attempt was made to evaluate the magnitude of such an effect.

Ten specimens were prepared. Three of them were of the standard variety, each containing a pair of scratched marks to define the 0.020-in. gage length at the base of the notch. The other specimens contained similar scratches and, in addition, contained various numbers of scratches between, and parallel to, the scratches defining the gage length. Each of the ten

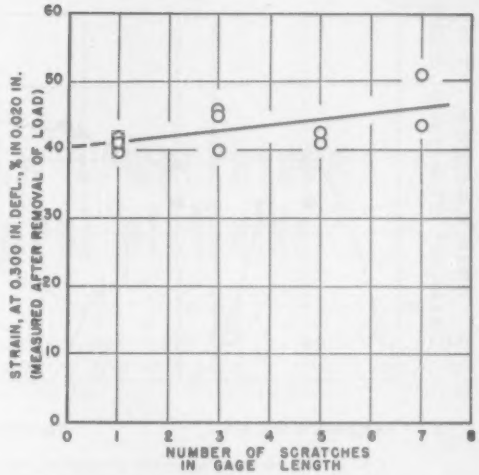

Fig. 8 Effect of additional scratches within the gage length upon measured strain

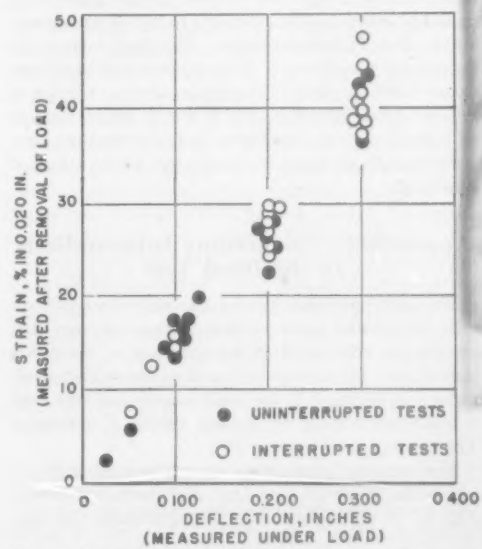

Fig. 9 Influence of interruptions during bending on measured strain

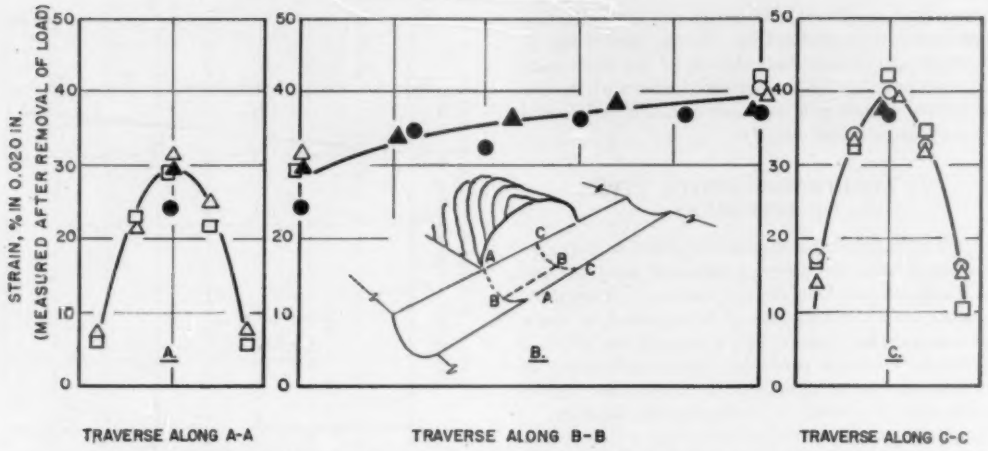

Fig. 10 Distribution of strain throughout the notch at 0.300 in. deflection, as-welded condition
(The 5 symbols refer to 5 individual specimens.)

specimens was bent in the usual manner (including interruptions) to a deflection of 0.300 in. The notch strain was then measured over the 0.020-in. gage length.

The results of the measurements are shown in Fig. 8. In this plot, it must be explained, the standard specimen containing no extra scratches is represented as containing one scratch within the gage length. (Each of the two scratches defining the gage length is considered to contribute one-half scratch.) In similar fashion, the specimens containing six superfluous scratches (a total of eight including the standard marks) are designated as containing seven scratches in the gage length. It will be noted in Fig. 8 that an increase in the number of scratches in the gage length tends to induce an increase in the value of measured strain. The effect, however, is fortunately a small one. In the figure a curve has been drawn to fit the data. Its extrapolation to a value of zero scratches (corresponding to a gage length marked off without the use of scratches) indicates that the error is an exceedingly small one in the case of the standard specimen.

Appendix 2. Concerning Interruptions in the Bend Test

The practice of interrupting the bend tests periodically to measure notch strains raises a question concerning the effect of such interruptions on the strain indications. To answer such a question, welded specimens were prepared in the usual manner and were bent without interruption to various values of deflection. The strains were then measured.

The results of these tests are represented in Fig. 9 which also shows the data from the interrupted tests of Fig. 5. It will be seen that the strain-deflection relations for the two types of tests are in close agreement. Accordingly, the use of the more convenient interrupted tests would appear to be justified.

Appendix 3. Strain Distribution in the Notch

Early in the investigation it appeared desirable to determine the site of most intense straining in the notch. Accordingly, five specimens were devoted to an exploration of strain distribution. After a deflection of 0.300 in. the longitudinal strains were measured along three separate traverses in the notches of two specimens and along two of these traverses in the remaining three. The results of the exploration and the locations of the three traverses are shown in Fig. 10.

Part C of the figure represents a traverse across the surface of the notch at the center line of the weld. Along this traverse it is clear that the greatest value of strain occurs at the base of the notch.

Part A of the figure shows the strains on a similar traverse located at the edge of the weld crown. In this case again the greatest value of strain is found to occur at the base of the notch. It is less, however, than the corresponding value on the center line.

Part B of Fig. 10 represents the strains observed on a traverse along the base of the notch from the center line of the weld to the edge of the crown. The greatest value of strain is seen to occur on the center line.

From these tests, then, it would appear that the greatest intensity of longitudinal strain is to be found at the base of the notch on the center line of the weld. This, of course, is the location which might have been anticipated. The remainder of the investigation was devoted to a study of this region.

Microcracks and the Low-Temperature Cooling Rate Embrittlement of Welds

The results of tensile, fatigue and impact tests are presented together with a discussion of certain features of the microcracks which are associated with embrittlement produced by too rapid cooling following welding

by A. E. Flanigan and M. Kaufman

1. INTRODUCTION

THE welding literature of recent years contains references to an important and previously unrecognized type of embrittlement affecting mild steel welds.[1-4] It is now apparent that welds may be embrittled by too rapid cooling through a temperature range considerably below that associated with the transformation of austenite following welding. It is also clear that this "low-temperature cooling rate embrittlement" is related to a fine-scale fissuring of the weld metal. The fissuring, it appears, is induced by an as yet incompletely understood mechanism in which a dominant role is played by the hydrogen content of the weld.

That this type of embrittlement has only recently attracted attention is indicated by an apparent absence of references to the subject in the literature prior to 1947. Since then, however, there have appeared the important papers by Bland[1] and by Rollason and Roberts.[2] Bland worked with mild steel while Rollason and Roberts dealt with the same material and, in addition, studied the effects of certain alloying elements. Another excellent paper by Steinberger, De Simone and Stoop[5] is concerned with what appears to be a closely similar type of embrittlement affecting steels of high hardenability.

For several years an investigation of low-temperature cooling rate embrittlement has been underway at the University of California at Los Angeles.* An earlier paper[2] based on this study was concerned mainly with an exploration of factors which influence embrittlement through their effects on low temperature cooling. In that paper it was shown that the cooling rate may be of critical importance even at temperatures below 400° F. It was also demonstrated by means of cooling rate measurements on affected welds that certain welding conditions commonly met in practice can be expected to produce embrittlement. In the earlier paper all evidence of embrittlement was based on the use of longitudinal notched-bend tests performed at −100° F.

The present paper, a sequel to the earlier one, deals in the main with two subjects. In the first place, it describes the embrittlement indications revealed by other types of tests. These include room-temperature bend tests, tensile tests, fatigue tests and notch-impact tests. Secondly, it deals with the detection, appearance and distribution of the microcracks which are associated with embrittlement. Some of the observations to be described are similar to those of other investigators and are related for their value as confirming evidence. Other findings lie in fields not previously explored.

Throughout the paper, the terms "microcracks," "fissures" and "microfissures," all of which have been used by other writers, will be used interchangeably to denote the characteristic internal defect associated with low-temperature cooling rate embrittlement.

In the work about to be described the welds were deposited on semikilled $^3/_4$-in. A285C plate from the same heat as was used in the work of Reference 2. This material contained 0.19% C, 0.33% Mn, 0.07% Si, 0.03% S and 0.015% P. With the exception of the fatigue specimens, all of the E6010 welds were deposited with $^5/_{16}$-in. electrodes at 170 amp., 25 v. and an arc speed of 7.7 in. per minute.

2. BEND TESTS AT ROOM TEMPERATURE

Since in the earlier work the bend tests had been conducted at −100° F., it was desired to repeat certain of them at a higher temperature to determine if the earlier indications of embrittlement might not have

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* The investigation has been supported by the Welding Research Council of the Engineering Foundation and by the Research Committee of the University of California at Los Angeles.

been peculiar to the low testing temperature employed. In the new tests, conducted at 70° F., it was found in general that the indications of embrittlement were nearly as severe as had been noted at −100° F.

Figure 1 illustrates the typical similarity of the results obtained at the two temperatures. It refers to tests on a series of air-cooled bead-on-plate E6010 specimens which differed only with respect to weld length. (Such tests are of interest since the rapidity of low-temperature cooling is strongly dependent on the ratio of specimen size to heat imput. This ratio may be controlled by varying the length of the weld on a specimen of fixed size, a decrease in weld length producing an increase in cooling rate.[2]) Figure 1 reveals that the indications of embrittlement at −100° F. were closely paralleled by those at the higher temperature. In both cases, it will be seen, the short welds failed at low values of bend angle.

Examination of specimens similar to those of Fig. 1 disclosed that no microcracks were present in the 5-in. welds. Many, however, were detected in the $2^1/_2$-in. length. The 4-in. welds constitute a borderline case which is discussed in Section 10.

The dimensions of the specimens associated with Fig. 1 are shown in the sketch in the figure. The notch, not shown, was of the same geometry as that employed throughout the work of Reference 2. It consisted of a transverse U-shaped groove of $^1/_{16}$ in. radius cut across the entire width of the specimen to a depth 0.020 in. below the plate surface. The tests were performed four days after welding.

At this point it is perhaps desirable to explain why the criterion for failure selected for use in Fig. 1 was different for the 70° F. tests than for those at −100° F.

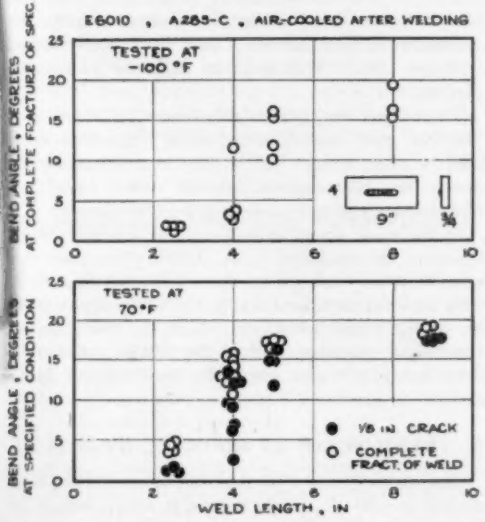

E6010 , A285-C , AIR-COOLED AFTER WELDING
TESTED AT −100 °F
BEND ANGLE , DEGREES AT COMPLETE FRACTURE OF SPEC
9"
¾
TESTED AT 70 °F
BEND ANGLE , DEGREES AT SPECIFIED CONDITION
½ IN CRACK
COMPLETE FRACT. OF WELD
WELD LENGTH , IN

Fig. 1 Effect of weld length on E6010 bend-test behavior at 70° F. and at —100° F.

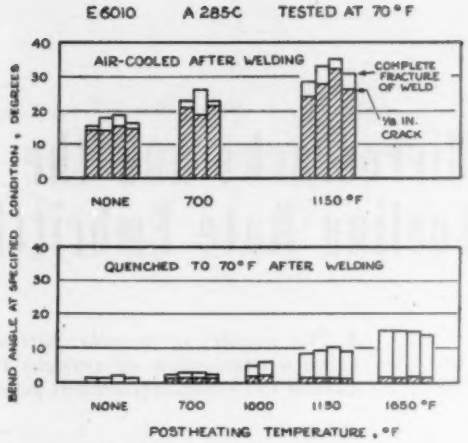


Fig. 2 Effect of postheating on damage induced by quenching following welding

In the tests at the lower temperature, complete and abrupt fracture of the entire specimen was precipitated by the first cracking of the weld.* At 70° F., however, the propagation of weld-metal cracks occurs in a relatively leisurely fashion and their growth is often arrested when they reach the heat-affected zone. When, as in the present case, one's concern is with the behavior of the weld rather than with that of the entire specimen, it seems desirable to use as the criterion of failure either the appearance of the first sizable crack in the weld or the growth of a crack entirely across it. These are the criteria used in Figs. 1 and 2.

Figure 2 shows another example of the embrittlement indications obtained in room-temperature bend tests. It refers to two groups of E6010 specimens which were postheated after welding. The geometry of these specimens was the same as that for the specimens of Fig. 1 except that all of the welds were of 9 in. length. Some of the specimens were air-cooled following welding. No microcracks were produced by this procedure. The remainder, quenched in 70° F. water immediately after welding, contained numerous microcracks. Both groups were postheated and air-cooled before testing.

Figure 2 reveals that the performance of the fissured welds was not greatly benefitted by postheating at temperatures up to 1650° F. What benefit there was appears to have been associated with the weld metal's resistance to crack propagation rather than with its ability to resist crack initiation. Since postheating is incapable of healing weld-metal fissures,[2,3,5] the behavior revealed in Fig. 2 is of course not surprising.

* This statement applies under the conditions encountered in Fig. 1 and in Reference 2. Under certain other conditions, however, notably after postheating, the course of fracture may be altered. The notch-resistance of the heat-affected zone may be so greatly enhanced by the treatment that fractures which originate in the weld metal are stopped abruptly in the heat-affected zone even in tests at −100° F.

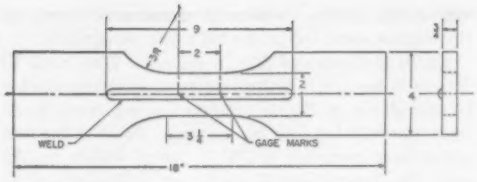


Fig. 3 Tensile-test specimen

3. TENSILE TESTS

When the severely adverse influence of microcracks on notched-bend behavior had become evident, it was wished to assess their influence under other types of loading. Accordingly, a number of tensile, fatigue and notch-impact specimens were prepared and tested. The tensile studies are described in this section.

The geometry of the tensile test specimen is shown in Fig. 3. In its preparation, a 9-in. weld of the bead-on-plate variety was deposited on a piece of $^3/_4$- x 4- x 18-in. plate. Later the test section was milled to a width of 2 in. The weld crown was not removed. The tests were conducted at room temperature either four or five days after welding. The results of the tests are shown in Fig. 4 where each bar represents the behavior of a single specimen. The seven groups of specimens are discussed in the following paragraphs.

The specimens of Group A, welded with E6010 electrodes and air-cooled, contained no microcracks. As indicated in the figure, these welds fractured at an average value of about 40% elongation.

The specimens of Group B also contained E6010 welds but were quenched in 70° F. water after welding. They contained many microcracks. These welds fractured at elongations averaging only about 8%.

Prior to welding, the specimens of Group C were cooled to −100° F. in a box chilled by dry ice. Upon removal from the box, they were immediately welded at room temperature (70° F.) with E6010 electrodes. They were then replaced in the box to cool in air on a wooden surface. During cooling, the temperature of the air in the box varied considerably. It was not measured but was known to lie in the range between 70 and −100° F. (This procedure was intended to simulate welding under conditions of low atmospheric temperature such as are sometimes encountered in cold climates.) As would be anticipated, low-temperature cooling was considerably accelerated by this procedure. Examination revealed that microcracks were produced, though not as abundantly as in the water-quenched specimens of Group B. As revealed in Fig. 4, the tensile behavior of these specimens was little better than that of Group B, the welds fracturing at an elongation of about 12%.

Upon the basis of tests A, B and C it must be concluded that, at least for the conditions tested, the embrittling influence of microcracks is clearly evident under direct tensile loading.

We now direct out attention to the specimens of groups D and E. These were in all respects similar to those of groups A and B, respectively, except that before testing they were postheated for three hours at 1150° F. followed by air-cooling. According to Fig. 4, both groups appear to have benefitted from postheating. It will be noted, however, that in the case of Group E which had been quenched following

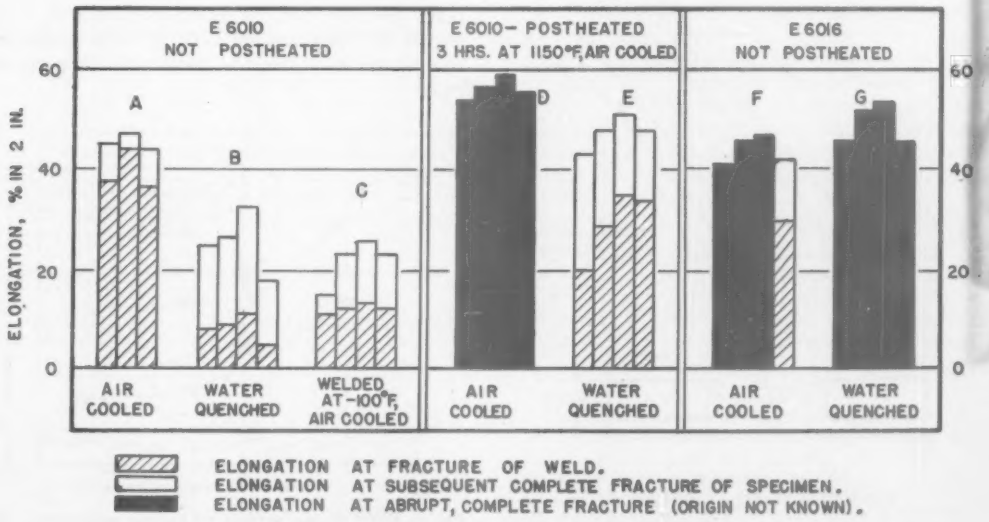


Fig. 4 Effects of various treatments on tensile-test behavior

welding the welds fractured at elongations somewhat less than those characterizing the air-cooled and non-postheated welds of Group A.

On the basis of tests D and E, then, it must be concluded that the tensile tests confirm earlier bend-test indications concerning the permanency of damage induced by microcracking. It appears, however, that the indications of damage are less severe in the tensile tests. (Compare with Fig. 2.)

Groups F and G consisted of air-cooled and water-quenched specimens bearing E6016 ("low-hydrogen") welds. It will be seen that the performance of the quenched specimens was not inferior to that of the air-cooled group. This observation again confirms earlier indications based on notched-bend tests.[2]

Before proceeding, it is of interest to note an interesting aspect of Fig. 4. It may be seen that, with only a single exception, the 12 specimens of groups D, F and G fractured in a different manner than did the 15 specimens of groups A, B, C and E. In the latter cases the fractures originated in the weld metal and were arrested outside the weld. In the former cases, however, the fracture of the entire specimen was instantaneous. Thus the performance of the weld was less, if any, inferior to that of the remainder of the specimen. While the explanation of this distinction is not clear, it should be noted that only the specimens of group D, F and G were characterized by the combination of low hydrogen content[4] and the absence of microcracks.

4. FATIGUE TESTS

To determine the effect of microcracks under the influence of alternating stresses, two groups of all-weld-metal specimens were prepared and tested in the manner described in the following paragraphs.

E6010 electrodes of $^5/_{32}$ in. diameter were used to deposit 9-pass welds in the grooves of specimens similar to that shown in Fig. 5. Before welding, these specimens were divided into two groups. Those of the first group were quenched in 70° F. water within 10 sec. after the completion of each pass. This procedure induced a large number of microcracks in each pass (as verified by subsequent microscopic examination). The remaining specimens were allowed to cool in air for 10 min. after each pass before being quenched in water. The 10-min. period of air-cooling insured that these welds were free from microcracks (also checked by examination).

After the completion of welding, an all-weld metal fatigue specimen was cut from the central region of each weld. The dimensions of these specimens are also shown in Fig. 5. The specimens were then tested to destruction in a rotating cantilever apparatus at 10,000 rpm.

The behaviors of the two groups of specimens are depicted in Fig. 6 where they are compared with the performance of a third set cut from the parent plate. It will be noted that the presence of microcracks has a strongly adverse effect on the fatigue strength of the welds. For a life of 5×10^6 cycles, the decrease in strength is about 40%.

Figure 6 also affords another interesting observation. It will be seen that the performance of the sound weld metal is superior to that of the parent plate. For a life of 5×10^6 cycles the strengths are about 44,000, 32,000 and 26,000 psi., respectively, for sound weld metal, for the parent plate, and for weld metal containing microcracks. The writers do not recall any previous reports of such a high fatigue strength for mild steel welds. It is intended, when the opportunity presents itself, to extend the fatigue tests to include specimens designed to fail in the heat-affected zone as well as in the weld metal and in the parent plate.

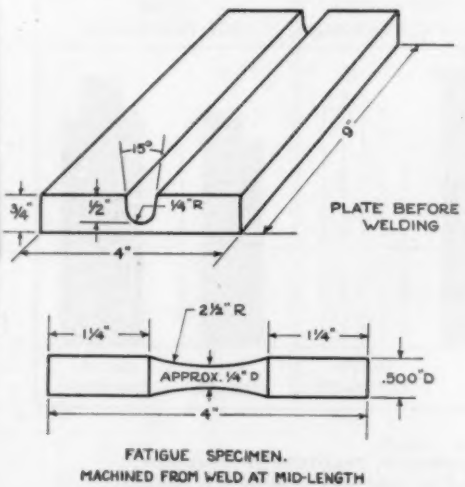


Fig. 5 All-weld metal-fatigue specimen

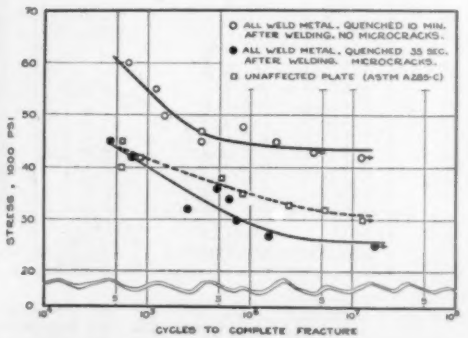

O ALL WELD METAL, QUENCHED 10 MIN. AFTER WELDING. NO MICROCRACKS.
● ALL WELD METAL, QUENCHED 35 SEC. AFTER WELDING. MICROCRACKS.
□ UNAFFECTED PLATE (ASTM A285-C)
STRESS, 1000 PSI
CYCLES TO COMPLETE FRACTURE

Fig. 6 Effect of microcracks on fatigue performance of E6010 welds

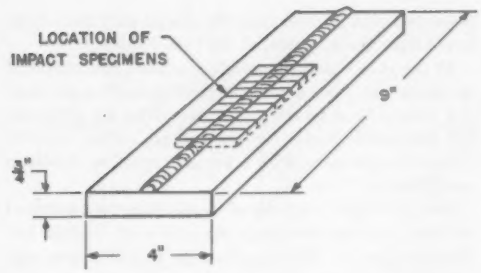


Fig. 7 Location of impact specimens in bead-on-plate weld

5. NOTCH-IMPACT TESTS

To determine the influence of microcracks under impact loading, a series of small impact specimens was prepared. The material for the specimens was sawed from E6010 bead-on-plate welds according to the arrangement shown in Fig. 7. The specimens were then machined to the dimensions shown in the upper portion of Fig. 8. It will be noted that the dimensions are those of a half-thickness Charpy specimen containing a half-depth Izod notch. The thickness and notch depth were such as to cause the weld metal to extend 40% of the way through the region under the notch. As indicated in the figure, the notch was located entirely within the weld.

A portion of these specimens was prepared from welds which had been air-cooled following welding, thus insuring the absence of microcracks. The remainder were cut from welds which had been quenched in 70° F. water immediately after welding. These latter of course contained numerous microcracks. After preparation, the specimens were placed in a Charpy-type testing machine and were broken at a hammer energy of 110 ft-lb. The testing temperatures ranged from 75 to −100° F.

Figure 8 shows the impact behaviors of these E6010 specimens along with that of a set of quenched E6016 welds. (The latter were known to bear no microcracks even after quenching.) As might have been anticipated, the adverse effects of microcracks are clearly evident.

6. MICROCRACKS IN WELDING PRACTICE

Since in the main the preceding work had been limited to bead-on-plate welds and to small specimens, it was considered desirable to determine if similar fissuring occurred in welds made under conditions more typical of welding practice. Accordingly, a 6-pass butt weld and an intermittent fillet weld, both air-cooled, were studied.

The butt weld was deposited on $^3/_8$-in. plate employing $^3/_{16}$-in. E6010 electrodes and an interpass temperature of 70° F. The specimen, 18 in. square after welding, was fabricated from two 9- x 18-in. halves. The double-V groove contained an included angle of 70 degrees. Three passes were deposited on each side of the plate. After each pass the specimen was allowed to cool in air for 10 min., thus reaching a temperature of about 160° F. It was then quenched in 70° F. water. (Quenching was employed to reduce the waiting time between passes. It is believed that it did not affect the results. Compare with Section 4.) These butt welds were subsequently sectioned and were found to contain large numbers of micro-cracks.

The fillet weld was deposited in a single pass in a T-joint formed from two long pieces of $^3/_8$- x 4-in. plate. It consisted of 3-in. increments spaced on 9-in. centers. This weld was deposited with $^3/_{16}$-in. E6010 electrodes and was cooled in air. Upon examination, it also was found to contain numerous micro-cracks.

It should be noted that, in both of the cases just described, the work was much less massive than that sometimes encountered in welding practice. In heavy structures, low-temperature cooling will be still more rapid and, as a consequence, even greater susceptibility to cracking can be expected. One is led to suspect that microcracking, though unrecognized, may be common in welding practice. Perhaps the occasional failures of apparently sound welds have been related to the presence of such defects.

At this point it is of interest to describe an observation on a multi-pass E6016 weld. The weld was deposited in a manner identical with that for the water-quenched E6010 welds used in preparing the

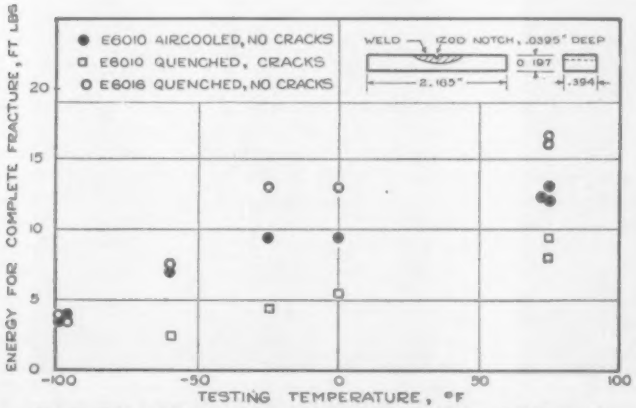


Fig. 8 Effect of microcracks on notch-impact behavior of weld metal

fatigue specimens of Section 4. The first three passes of the E6016 weld were found to be free from microcracks, but the later passes exhibited a number of them. This behavior might at first seem surprising since bead-on-plate E6016 welds had earlier been found immune to fissuring even when quenched in liquid nitrogen. However, it confirms a similar observation by Rollason and Roberts.[3] As they have suggested, one is led to suspect a significant build-up of hydrogen in the later passes of a "low-hydrogen" multipass weld.

7. THE DETECTION OF MICROCRACKS

Since microcracks probably occur in mild steel welds under conditions sometimes met in practice, one wonders then why there has not been a greater awareness of the phenomenon of microcracking. The explanation probably lies in the fact that the detection of microcracks is not a simple matter.

In the present work on mild steel, the writers have found that weld metal microcracks are not detectable by means of magnetic particle inspection or by the use of penetrating liquids. This is not surprising in the case of an unsectioned weld since the defects lie well below the surface. (See Section 9.) Even in the case of a mechanically polished section, these methods do not appear to be useful. It is to be noted, however, that Steinberger, DeSimone, and Stoop,[5] who studied atomic-hydrogen welds in a highly hardenable steel, were able to reveal fissures by applying the magnetic particle method to sectioned welds. It is suspected that in their case the cracks may have been larger than those typical of mild steel welds.

In the case of a mechanically polished but unetched specimen cut from a weld in the "as-cast" condition, the writers have found that microcracks are generally not discernible under the microscope. This observation is in agreement with a similar report by Rollason and Roberts.[3]

The prolonged etching of a mechanically polished section produces markings suggestive of fissures but identification is difficult since such indications also resemble patterns characteristic of the as-cast structure of sound welds (i.e., certain of the dark interdendritic and grain boundary markings). This observation is in agreement with a similar report by Bland.[1] It appears, however, that under certain conditions, Rollason and Roberts[3] were able to detect fissures in mechanically polished and etched specimens.

Bland[1] revealed the presence of microcracks by the bending of the weld containing them. This caused the fissures to open up and to become visible on sections through the weld.

It has been the experience of the writers that microcracks are most conveniently detected on sections which have been electrolytically polished but not etched. Perchloric acid–acetic anhydride and chromium trioxide–acetic acid solutions have been used as electrolytes. The specimen shown in Fig. 9 was etched after electro-polishing. The unusually large fissure which appears in the figure was just as prominent before etching. Because of its great width (exaggerated by electro-polishing) it can be readily distinguished from the surrounding structure even in the etched condition. Had the polishing been done mechanically, however, the fissure in Fig. 9 would not have been discernible before etching. After etching, it would have been so narrow that it would have been difficult to distinguish it from the surroundings. It appears that mechanical polishing tends to obscure micro-

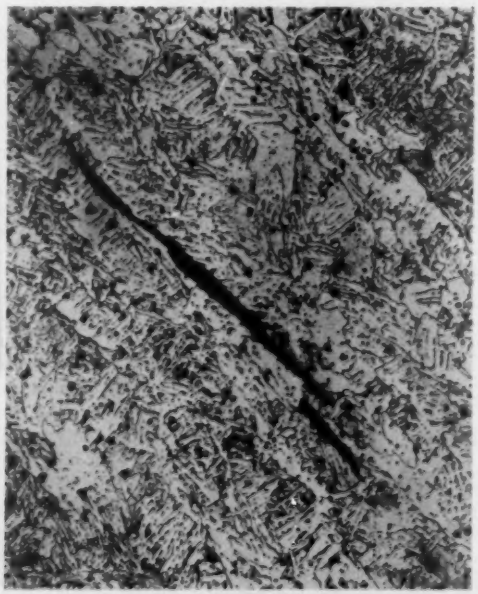


Fig. 9 Typical microcrack in E6010 weld metal. Electrolytic polish, nital etch, 250 ×

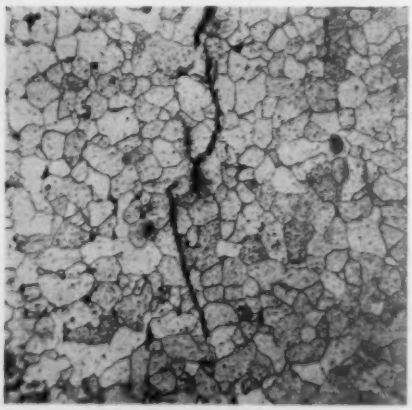
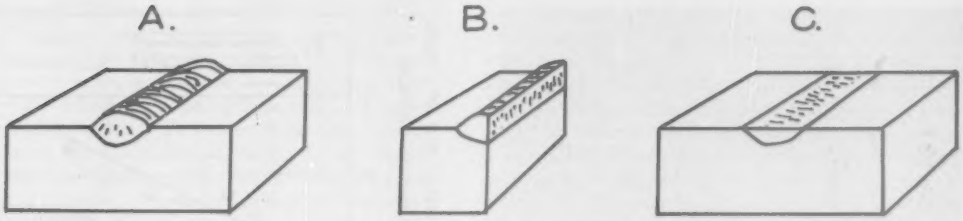


Fig. 10 Microcrack in E6010 weld metal recrystallized at 1650° F. Mechanical polish, nital etch, 250 ×


A.
B.
C.
ABOUT 5 FISSURES PER SECTION
ABOUT 75 FISSURES PER INCH LENGTH OF SECTION
ABOUT 600 FISSURES PER INCH LENGTH OF SECTION

E 6010 bead-on-plate weld, quenched in 70° F. water immediately following completion of welding

Fig. 11 Orientation of fissures and the dependence of their frequency on the plane of sectioning

cracks while electro-polishing accentuates them. The greater the duration of electro-polishing, the greater becomes the apparent prominence of the fissures.

In the case of a recrystallized weld, mechanical polishing followed by etching may be used successfully since the interdendritic markings are no longer present and they can not be confused with the fissures. The specimen of Fig. 10 was polished mechanically before etching. It represents an E6010 weld recrystallized at 1650° F. Fissures located in the recrystallized portions of multipass welds present a similar appearance.

8. THE ORIENTATION OF MICROCRACKS

The apparent density of microcracks (i.e., the number observed per unit area) in a sectioned weld was found to vary with the orientation of the plane of polish. Figure 11 shows the variation for the case of a 9-in. E6010 bead-on-plate weld which had been quenched immediately after welding. (The quantitative values shown in the figure apply to the mid-length region of the weld.)

It is of interest to note in Fig. 11 that relatively few fissures are to be found on Section A which is transverse to the axis of the weld. Perhaps this is in part the reason why the occurrence of fissuring in mild steel welds has received so little attention until recent years. Many laboratories tend to select transverse sections for microscopic examination.

Figure 11 also indicates the orientations of the fissure traces on each of the several sections. As indicated, the traces were essentially parallel on the sections designated B and C. Figure 12 is a photomicrograph of a group of microcracks seen on a section of Type B. The typical parallelness is evident.

From Fig. 11 it may be deduced that the fissures generally lie in transverse planes, i.e., in planes perpendicular to the axis of the weld. Such a conclusion is in agreement with a similar belief expressed by Bland.[1] A transverse orientation is not surprising since it coincides with interdendritic paths which may be presumed to be regions of weakness (and perhaps of high hydrogen concentration). Furthermore, large tensile stresses are known to act across transverse planes during the cooling of the weld.

It need not be thought that the orientation relationships shown in Fig. 11 are characteristic of quenched specimens alone. The examination of air-cooled bead-on-plate welds prepared under conditions promoting fissure formation has shown the same orientations, though not the same fissure densities, as are exhibited by the water-quenched weld of Fig. 11.

9. THE DISTRIBUTION OF MICROCRACKS

It is of interest to consider the manner in which the distribution of microcracks is related to their location on a section through the weld. The writers have examined many bead-on-plate welds and have observed hundreds of microcracks. It has been observed that the fissures tend to concentrate in the interior of the weld metal and that they seldom, if ever, occur in regions near the external surfaces and the fusion line. Such a distribution supports the belief that hydrogen is a factor of prime importance in the formation of microcracks. Near external surfaces one might expect the hydrogen concentration to be considerably reduced by escape to the atmosphere during cooling. Near the fusion line the hydrogen content might be reduced by diffusion into the parent metal.

The fact that low-temperature microcracks occur only in the interior of a weld is of course an insidious one since it makes detection difficult by external examination alone. This is perhaps one of the reasons why the prevalence of this type of defect has not been more generally recognized.

There is another interesting consequence of the fact that the marginal regions tend to be sound even in badly fissured welds. In tests in which a notched specimen is used to assess weld ductility, it is conceivable that misleading results might be obtained were the notches to be located in a fissure-free region as, say, near the fusion line of a bead-on-plate weld.

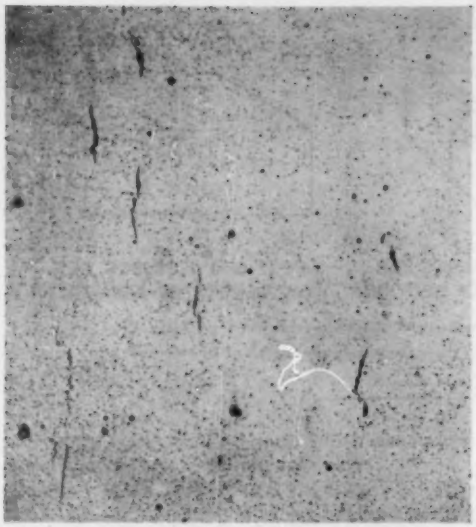


Fig. 12 Typical microfissures in a quenched E6010 weld. Electrolytic polish, no etch, 75 ×

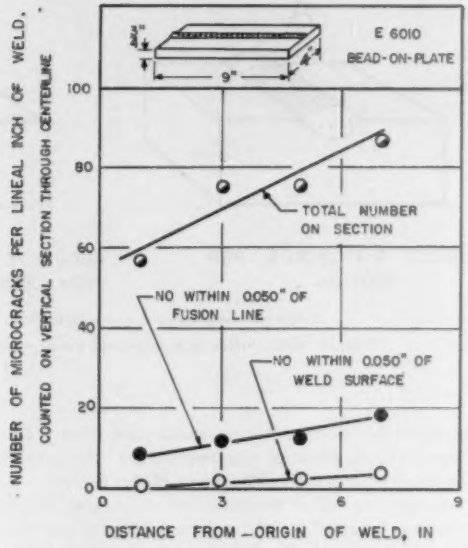


Fig. 13 Distribution of microcracks in E6010 deposit quenched after welding

Some quantitative observations concerning the distribution of microcracks are summarized in Fig. 13. These data are average values for two E6010 bead-on-plate specimens quenched immediately after welding. Sections similar to Case B of Fig. 11 were removed from various locations along the lengths of the welds and were examined for the presence of microcracks. The upper curve of Fig. 13 shows the effect of location along the length of the weld on the apparent abundance of fissures. It may be noted that the defects are most numerous near that end at which welding was completed, i.e., at the end cooled for the shortest time prior to quenching. They are least numerous near the origin of the weld—this despite the more rapid (and hence less favorable) elevated-temperature cooling which may be presumed to have occurred near the origin. This distribution suggests once again the importance of low-temperature cooling and the probable importance of hydrogen in the cracking mechanism.

The two lower curves of Fig. 13 show the frequency with which microcracks were found near the margins of the weld. It will be seen that the marginal fissures increase in frequency as the end of the weld is approached. Thus these curves illustrate the general tendency for the depth of the fissure-free region to decrease with an acceleration of low-temperature cooling. In the case of welds cooled sufficiently slowly to avoid fissure formation altogether, it may be supposed that the margins have merged to occupy the entire cross section.

The knowledge that the frequency of fissures varies with the severity of cooling prompts one to wonder concerning the manner in which weld ductility may be expected to vary with the abundance of fissures. As evidence, consider Fig. 4. The specimens air-cooled after welding at −100° F. (Group C) contained relatively few fissures compared to the water-quenched specimens of Group B. In spite of this, however, it is seen that the tensile performances of the two groups were not greatly different. In each case there appeared to be considerable embrittlement. Notched-bend tests seem to produce even greater similarity of behavior in such cases. It would appear, then, that a relatively low intensity of fissuring is no grounds for optimism. In certain applications, a small number of fissures may be nearly as undesirable as a much greater number.

10. THE BORDERLINE CONDITION

It seems clear that treatments which produce microcracks in bead-on-plate welds cause a marked impairment of ductility. Throughout the investigation there have been no exceptions to this rule. On the other hand, impairment has been noted in certain cases in which microcracking was not evident before testing. In these cases the cooling rates were only slightly slower than those required to induce visible cracking. This section deals with one of these borderline cases.

Consider Fig. 1. It is seen that an abrupt transition in ductility characterizes weld lengths in the neighborhood of 4 in. Careful examination of electropolished specimens disclosed that a considerable number of microcracks were present in $3^1/_2$-in. welds and in those of shorter length, but that none appeared in the 4-in. welds. It seemed that the embrittlement of the 4-in. welds was occurring in the absence of microcracking.

To clarify the matter, a series of room temperature bend tests was made on unnotched specimens otherwise similar to the 4-in. welds of Fig. 1. It was known from earlier tests on unnotched specimens that, in the absence of microcracks, the fractures ordinarily tended to originate on the rough surface of the weld. In the testing of the 4-in. welds, however, it was apparent that the first fractures originated in the interior precisely in the region where microcracks would have been expected had they been present.*

It would appear then that, although no microcracks could be detected before straining, there existed in these specimens either a number of submicroscopic cracks or a predisposition to the formation of microcracks upon straining.† This evidence, together with that of Fig. 1, would seem to indicate that the apparent absence of microcracks is no guarantee of the absence of embrittlement in the case of cooling rates in the borderline region. Similar indications were obtained when another method was employed to approach the borderline condition.

11. THE ROLES OF HYDROGEN AND OTHER CONSTITUENTS

Other investigators have reported that welds made with low-hydrogen electrodes exhibit minimum susceptibility to microcracking.[1–3,5] For this reason and for others as well they have suggested the importance of hydrogen in the fissuring mechanism. In the present investigation these suspicions have been abundantly supported by various indications some of which are summarized below.

1. It was repeatedly observed that no fissuring resulted when bead-on-plate E6016 welds were subjected to even the most drastic cooling. A 3-in. weld, for instance, developed no fissures when quenched in liquid nitrogen immediately after welding. (As noted in Section 6, however, it appears that complete immunity cannot be expected of multipass E6016 welds.)

2. It was found that bead-on-plate E6016 welds became subject to fissuring and embrittlement when hydrogen was introduced during welding by injecting a jet of the gas into the welding arc. Similar effects were produced when hydrogen was introduced by soaking the E6016 electrodes overnight in water before welding. In both of these cases embrittlement and fissuring were absent from air-cooled welds but were developed by water-quenching after welding.

3. The importance of hydrogen is also strongly suggested, as has been pointed out in Section 9, by the distribution of microcracks in embrittled welds. It would seem difficult to reconcile the observed distribution with an explanation not emphasizing the role of an agent of high diffusability at low temperatures.

4. It was found that, when elevated-temperature cooling conditions were approximately the same, the weld metal hardness values for embrittled, fissured welds were very little different than those for the fissure-free variety. (In the case of 9-in. bead-on-plate welds, for instance, the hardness for the quenched condition exceeded that for similar air-cooled welds by no more than one point on the Rockwell 30 T scale.) This observation confirms a similar finding by Steinberger, De Simone and Stoop.[5] Thus, the mechanism responsible for fissuring and embrittlement would appear to have little influence on hardness. Such an indication is consistent with the suspected role of hydrogen since the latter is known to have little influence on the hardness of steel.[4,6,7]

While it was apparent that hydrogen introduced during welding promoted susceptibility to fissure formation, it was found that the pickling and cathodic charging of sound welds following cooling produced no fissures. (Pickling was accomplished by a 10 hr. exposure to 10% sulphuric acid at 120° F. while cathodic charging involved a $2^1/_2$ hr. exposure to the same medium at room temperature with a current density of 0.45 amp. per square inch.) It would appear that hydrogen imparted during welding may be more potent than that introduced after cooling.

It has been suggested by Rollason and Roberts that the nitrogen content of the weld may be a factor in fissuring.[3] In the present work efforts made to detect any influence of this element have produced negative but as yet indecisive results. E6010 bead-on-plate welds were found susceptible to microcracking even when produced in an atmosphere of argon to limit nitrogen pickup. On the other hand, no fissuring resulted from the quenching of E6016 specimens during the welding of which a jet of nitrogen had been introduced into the arc in a manner similar to that mentioned several paragraphs earlier for the introduction of hydrogen.

One of course wishes to consider the possibility that the decomposition of residual austenite in the presence of hydrogen may be involved in the fissuring process. In the present study, however, efforts to detect such an influence have as yet yielded consistently negative results. The attempts have included methods similar to those used so successfully by Mallett and Rieppel[8] to detect the interplay of hydrogen and retained austenite in the underbead cracking and the toe-cracking of welds in hardenable steels. The attempts involved various sequences of cathodic charging and quenching in liquid nitrogen.*

It would appear then that, while one can scarcely question the importance of hydrogen content, it is not clear that either nitrogen or retained austenite is involved in the fissuring of mild steel welds. On the latter point, however, it cannot be said that such a possibility has been disproved.

It is intended in another paper to describe in more

* In notched specimens bearing microcracks the fissures are located in the same region as is the base of the notch. Thus, if these tests had been performed with notched specimens, it would have been difficult to distinguish between the tendency of fractures to start on a rough external surface and their tendency to originate in the interior at microcracks.

† A choice between these alternatives could perhaps be based on observations on postheated 4-in. welds but such tests have not as yet been made.

* With regard to all of the work related in this paper, no efforts were made to measure the hydrogen, nitrogen or retained austenite contents of the welds.

detail some of the evidence related above and to present certain other observations bearing on the mechanism of fissuring.

This section will be concluded with a reference to strain aging. The authors, who suspect that hydrogen may also be a factor in the strain-age embrittlement of welds,[8] examined some affected specimens. It appeared, however, that there were no indications of microcracking in the strain-aged welds.

12. SUMMARY AND CONCLUSIONS

This paper describes an extension of earlier work on a type of embrittlement induced in mild steel welds by too rapid cooling through the low-temperature range following welding. The principal findings and conclusions may be summarized as follows.

1. The indications of embrittlement obtained in earlier bend tests at −100° F. have been confirmed in similar tests at room temperature.

2. Evidence of weld impairment has also been revealed by fatigue tests, tensile tests and notch-impact tests.

3. It has been found that weld impairment is usually attended by the appearance of fine microcracks in the interior of the weld. In cases involving borderline cooling rates, however, embrittlement has sometimes been observed to occur in the apparent absence of fissuring. In these borderline cases it seems possible that fissuring may develop only after straining.

4. Methods for detecting microcracks have been described and discussed. The use of electrolytic polishing is recommended.

5. The suspicion that microcracks, though unrecognized, may frequently occur in welding practice has been supported by observations on a multipass butt weld and an intermittent fillet. It is suggested that low-temperature cooling rate embrittlement may be a matter of practical importance to the welding industry.

6. Certain observations concerning the distribution and detection of microcracks help to account for past failures to recognize the presence of these defects when they may have existed in welds.

7. Various observations support the belief that hydrogen is a prime factor in the mechanism of embrittlement. Attempts to demonstrate the importance of nitrogen and retained austenite, however, have as yet proved unsuccessful.

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A New Proposal for Steel Filler Wire for Welding

Tests of filler metal with core wires containing adequate quantities of deoxidizers such as manganese and silicon

by H. Sekiguchi

INTRODUCTION

HITHERTO, low-carbon steel wires, whose contents of other elements are very low, have been regarded as suitable filler wires for welding of mild steel. But the author thinks it a better practice to use steel wires containing adequate quantities of deoxidizers such as manganese and silicon. His proposal, based on the new idea and its experimental results, has been supported by Dr. S. Nishikiori, managing director of the Shin-Daido Steel Mfg. Co. Ltd. Now this type filler wires manufactured by the company are being supplied to the whole welding industry of Japan.

H. Sekiguchi is Professor of the Faculty of Engineering, Nagoya University, Japan.

DIAGRAM OF THE DEOXIDATION WITH MANGANESE AND SILICON

According to Körber and Oelsen,[1] in the state of equilibrium between the molten iron containing Mn, Si and O and the deoxidation products, reached at a

temperature just above the freezing point of iron, the relations between the composition showing Mn and Si contents of the molten iron and the form of deoxidation product are as follows (see Fig. 1):

Above the curve $G'F'$, *i.e.*, Field I—solid SiO_2.
Between the curve $G'F'$ and the curve $Q'D'$, i.e., Field II—FeO-MnO-SiO_2 liquid solution unsaturated with SiO_2.
Below the curve $Q'D'$, i.e., Field III—FeO-MnO solid solution.

Assuming that deoxidation product is saturated with silica, and starting from three equations[2] given by Körber and Oelsen in connection with Mn equilibrium, Si equilibrium and FeO distribution, the author derived three theoretical equations. Next, referring to the equation[3] given by H. Schenck, an equation was derived expressing the iso-oxygen-concentration line in the neighborhood of the curve $Q'D'$ and in Field II. Then, using these four equations, in Fig. 1 the author plotted the boundary curve $G'F'$ and many iso-oxygen-concentration lines for 1510° C., a temperature just above the freezing point of industrial iron or steel.

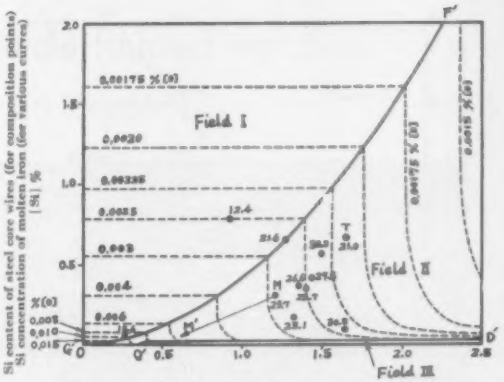
Field I
Field II
Field III
Si content of steel core wires (for composition points)
Si concentration of molten iron (for various curves)
[Si] %
Mn content of steel core wire (for composition points)
Mn concentration of molten iron (for various curves)
[Mn] %

Fig. 1 Relation between properties of weld metals and composition points showing Mn and Si contents of core wires used

Note 1: Black points, composition points; dotted lines, iso-oxygen-concentration lines; figures near black points, elongation values of weld metals obtained with the coated rod whose core-wire composition is shown by the black point
Note 2: The composition of core wire (e.g.M.) changes to the composition of weld metal (e.g.M.) in the case of welding

A NEW IDEA ON STEEL FILLER WIRE FOR WELDING

Though it is necessary to prevent the entry of atmospheric oxygen into molten metal in the course of steel welding, it is desirable further to induce forced deoxidation. In the author's opinion a suitable method of obtaining clean and excellent weld is to select the composition of filler wire as follows:

(*a*) To take the composition point showing Mn and Si contents of steel wire from within Field II of Fig. 1.
(*b*) To hold Mn and Si contents of steel wire in higher concentration depending on the composition and quantity of covering.

This method is also considered to be an economic way of preparing coated arc-welding rods of easy operation, and to be useful for gas welding and submerged arc welding, too.

EXPERIMENTS OF ARC WELDING WITH FILLER WIRES CONTAINING MANGANESE AND SILICON

The Mn and Si contents of the core wires prepared are shown with the composition points in Fig. 1. Some covering containing no ferromanganese was provided on these core wires (4 mm. diameter). Using such arc-welding rods, various properties of weld metals were investigated in accordance with the examination method of JES 9001. For example, elongation values are shown in Fig. 1. From these experimental results, the following tendencies were observed.

(*a*) When the composition point of the core wire was located in Field II, the increase of Mn, Si or both elements raised the apparent specific gravity, elongation and impact value of the weld metal deposited with the coated rod.

(*b*) But if the Mn and Si contents of the core wire became too large (as in the case of *T*), these properties of the weld metal sometimes deteriorated.

(*c*) The elongation and impact values of weld obtained with a core wire whose composition point was located in Field I were smaller than those obtained with one whose composition point was located in the neighborhood of the same iso-oxygen-concentration curve in Field II.

(*d*) Tensile strength and hardness increased with the Mn and Si contents of the core wire used.

Further, observing one-layer-fillet welds whose cooling rate was very high, the author found the following fact.

(*e*) In the case of using core wires having silicon contents as high as 0.3% or more, the so-called "striated structure" often developed in some portions of the fracture of the weld which was broken for test purposes, and, moreover, minute cracks appeared sometimes in some of these portions.

MANUFACTURE AND PRACTICAL USE OF NEW STEEL FILLER WIRES

Adopting the author's proposal* based on the new idea and its experimental results, the Shin-Daido Steel Mfg. Co. Ltd. started production of steel filler wires of the types indicated in Fig. 2, and the products

* There are three patents in Japan, in connection with the composition of these filler wires.

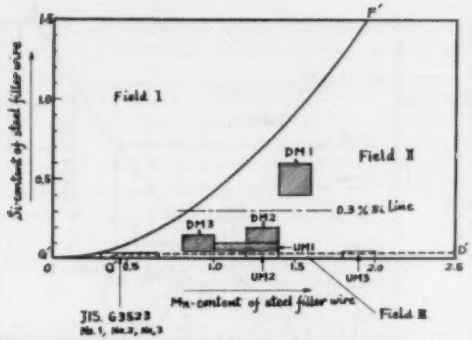

Fig. 2 Relations between Mn contents and Si contents of steel filler wires

Note: Hatched rectangles show the composition ranges of filler wires being made based on the author's proposal

were widely distributed to the welding industry for on-the-job examination. Table 1 shows only a few examples of many results reported. As seen from the same table, the filler wires DM2 and DM3 make superior coated electrodes for arc welding of mild steel; since they need no addition of ferromanganese to the covering mixture, the material cost of covering is by far smaller than when using the conventional core wire and covering mixture having ferromanganese. Besides, abrasion of the nozzle in a coating machine is slight. Accordingly, these wires are preferred by makers of coated welding rods; and, encouraged by satisfactory test results as shown in Table 1, the use of these coated rods is now spreading over the whole industry of Japan.

If ferromanganese or other ferro-alloy is added to the covering, the tensile strength of weld metal is elevated. Such electrodes are suitable to higher-tensile steel; therefore these kinds of welding rods are used for arc welding of rails and low-alloy steel supports for coal mines.

The filler wire DM1 finds use as the core wire of the light-coated gas welding rod for rails. DM2 and DM3 are adopted as gas welding rods for mild steel in many shipyards and other factories, while the wire DM2 or UM1 is generally recognized as good for submerged-arc welding of mild steel.

CONCLUSION

The author's new idea on steel filler wire for welding is founded on the theory of deoxidation with manganese and silicon. And its appropriateness was proved experimentally. When the welded part is cooled rapidly, however, it is desirable to hold the Si content of the filler wire below 0.3%.

The filler wires developed by the new proposal are now gaining great popularity in the industrial circles of Japan under the name of "Sekiguchi's Filler Wires" or "DM Type* Wires." The author hopes that his views will be fully discussed by world-wide experts for further development of the theory and its wider application.

Also, he expects that the full text of this article shall be published at the earliest opportunity.†

ACKNOWLEDGMENT

Sincere gratitude is hereby expressed to those who have kindly supported and cooperated with the author.

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* Daido Mansil Types.

† Memoirs of the Faculty of Engineering, Nagoya University, Vol. 3, No. 2 (October 1951), published by the Faculty (Rokunocho, Atsuta-ku, Nagoya, Japan).

Table 1—Results of Tension Tests on Weld Steel Made by Arc Welding of Mild Steel

Coated electrode used			Mechanical properties of weld metal		
Core wire	*Ferromanganese in covering*	*Examination method*	*Tensile strength, kg./mm.²*	*Elongation, %*	*Organization in which the examination was performed*
DM2	None	JIS G3524	48.2	27.3	The Osaka Tokosha Co. Ltd.
	None	JIS G3524	48.9	27.2	The Railway Technical Laboratory, Japanese National Railways
	5% Added	JIS G3524	54.3	26.8	The Kobe Shipyards & Engine Works, Central Japan Heavy Industries Co. Ltd.
DM3	None	JES 9001	50.9	27.1	The Tokyo Kako Co. Ltd.
	None	JES 9001	42.5	28.6	The Hakusan Tetsugyo Co. Ltd.

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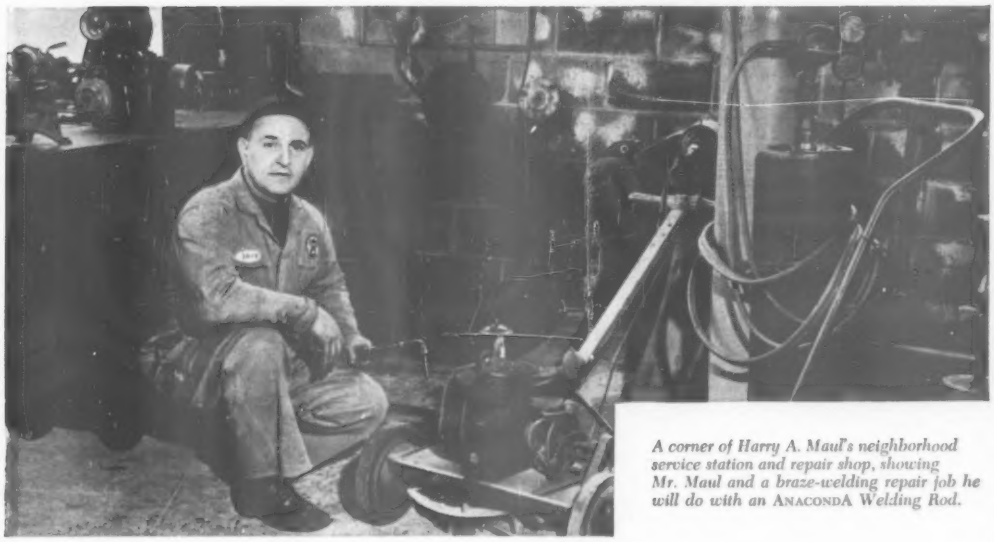

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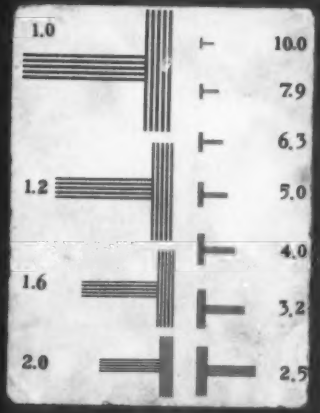

100 MILLIMETERS

INSTRUCTIONS Resolution is expressed in terms of the lines per millimeter recorded by a particular film under specified conditions. Numerals in chart indicate the number of lines per millimeter in adjacent "T-shaped" groupings.

In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and 100/20 = 5.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and 7.9 x 5 = 39.5 lines per millimeter recorded satisfactorily. 10.0 x 5 = 50 lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.

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